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EDITORIAL NOTES.

THE officers of the Geological Society of London for the current year have been elected as follows: President, Professor A. C. Seward; Vice-Presidents, Professor E. J. Garwood, Mr. R. D. Oldham, Dr. G. T. Prior, and Dr. H. H. Thomas; Secretaries, Mr. W. Campbell Smith and Mr. J. A. Douglas; Foreign Secretary, Sir A. Geikie; and Treasurer, Mr. R. S. Herries. The new members of the Council are: Mr. F. N. Ashcroft, Professor P. G. H. Boswell, Dr. F. H. Hatch, and Mr. H. Woods.

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IN the Report of the Council for 1921 the item of greatest interest to most geologists is the question of the *List of Geological Literature*. It is stated that the publication of the Subject-Index must be discontinued, and this will be a matter of universal regret. We would urge the Council to reconsider this decision, and to endeavour to devise some method for its continuance, even if in an abbreviated form. For our own part we would rather scrap the *Abstracts* than the Subject-Index, since the latter is of permanent value, while nearly everything in the *Abstracts* appears eventually in the *Quarterly Journal*.

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WE regret to learn that, owing to the greatly increased cost of production, the *Zoological Record* is in danger of being discontinued, unless a larger number of subscribers can be obtained. Fifty-five volumes (up to 1918) have been issued, and the volume for 1919 is in the Press. We call attention to this since the *Record* includes Palæontology, and now that the *Geological Literature* published by the Geological Society no longer includes an index of subjects, the *Zoological Record* should be of even greater importance than hitherto to Palæontologists. Those who do not require complete volumes can obtain separately the parts dealing with the groups in which they are interested. Further particulars may be obtained from the Secretary, Zoological Society, Regent's Park, London, N.W. 8.

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MR. G. V. COLCHESTER has been appointed to the post of Geologist on the Geological Survey of the Anglo-Egyptian Sudan in succession to Mr. C. T. Madigan, who now holds a lectureship in geology at Adelaide University.

ORIGINAL ARTICLES.

The English Eskers.

By Professor P. F. KENDALL, M.Sc., F.G.S.

THE discussion by Professor Gregory in the February GEOLOGICAL MAGAZINE of certain ridges of glacial deposits in various widely separated areas seems to call for some comment. I am not familiar with all the examples classified by Professor Gregory any more than he is, but a couple of examples visited by him, and that I have examined many times, may serve as tests of his trustworthiness as a field observer in Glacial Geology and his competence as a commentator upon the observations of others.

The first case is that of a remarkable drift ridge extending with little interruption for a distance of about 3 miles along the high Millstone Grit moorland overlooking the Wharfe Valley, from the vicinity of Ilkley down nearly to Guiseley. Professor Gregory selects for discussion an isolated segment known as Lanshaw, or Laneshaw, Delves, a name, as I shall show, of extraordinary significance to the geological investigator. Attention was drawn to these ridges by Russell,[1] who describes it as "composed of limestone-gravel", which he amplified in the *Geol. Surv. Mem.* 92, S.E., to "limestone-boulders mixed with pebbles and sand".

In the great memoir of the Yorkshire Coalfield the same author, apparently, on p. 780, remarks: "These mounds have been dug over for limestone, which they contain, so that their original form is partly lost; the limestone has been burnt on the spot, the ruins of old limekilns occurring at intervals, and stones and chert which have undergone the action of fire being scattered around."

Carvill Lewis, whose account is commended by Professor Gregory as the best (a judgment in which I do not concur), begins his description: "The eskers or sandbanks on top of the moor are known as Laneshaw Delves, and limekilns have been built upon them."

These descriptions are brief and give little detail, but a full and detailed description of the ridges is given in a very important paper unaccountably ignored by Professor Gregory. The authors, Messrs. Jowett and Muff (now Maufe),[2] devote two pages of their finely illustrated memoir to the description and interpretation of the ridges, which they follow Carvill Lewis in recognizing as the lateral moraine of a great Wharfedale Glacier. They remark that "Along much of its course it has been dug into and turned over for the limestone boulders which it contained".

It will be observed that every author cited mentions the occurrence of limestone boulders in the ridge. And the two selected for citation by Professor Gregory mention the lime-kilns.

[1] B.A. Report, 1873, Trans., p. 91.

[2] "The Glaciation of the Bradford and Keighley District": *Proc. Yorks. Geol. and Polyt. Soc.*, vol. xv, 1904, pp. 193–247.

Now let us have his version: After exact details of the position of Lanshaw Delves, "a bank about 650 yards long, 25 yards wide at the west end, and 50 yards wide at the east end; the height is 8 feet at the west and 15 feet at the east end; the trend is a little south of east; the south front is the straighter and higher. The summit of the Delves is irregular and hummocky, the depression sometimes giving it the character of a triple ridge."

Then follow very detailed observations of the constituents, boulders, exclusively of Millstone Grit, their arrangement, and a careful description of the shape of the stones. "The boulders are sometimes arranged in piles, but they show no arrangement in bands across the Delves." I suspect that the lime-burners had little incentive to arrange them in a systematic manner.

"The smaller pebbles include vein quartz, and jagged fragments of black chert; and all of these may have been derived from the Millstone Grit." (The jagged fragments of black chert, often crinoidal, could not have come from the Millstone Grit, but must have come from some outcrop of Lower Carboniferous in Upper Wharfedale.)

Now for Professor Gregory's judgment, uttered with a pontifical assurance in ludicrous contrast with the enormous lacunae in his data. "It is a moraine bank formed along the margin of a sheet of snow and ice that filled the depression in which lies Lanshaw Dam."

"The Delves are the remains of a moraine on the margin of an embryo corrie-glacier." His tone is catching, and provokes me to retort in the same tone of confidence, with this difference, that I am fortified by an intimate knowledge of the whole district, and of the whole length of the ridge or ridges, with many photographs and maps, and the concurrence of every geologist in Yorkshire—and they are many—who has examined the ground.

Lanshaw Delves is a portion of the lateral moraine of a great glacier that descended Wharfedale, bringing with it multitudes of boulders, large and small, of Carboniferous Limestone and many fragments of black crinoidal and other chert.

In the Middle Ages, when the only road from Skipton to Lower Airedale was a pack-horse track that left the valley at Uttley, near Keighley, and went over the hills towards Bradford, the Lanshaw Delves were the principal sources of lime for a large area about Bingley, Shipley, etc. The lime-burners rummaged and turned over the moraine in search of the limestone boulders, so that it is doubtful if any part of the Lanshaw Delves segment has escaped being ransacked, and it is hardly to be wondered at that Professor Gregory found the summit "irregular and hummocky, sometimes giving it the character of a triple ridge". But where was his geological eye? The depressions are in part the "Delves" (plural of Delf, a place where people "dig and delve"), whence the limestone-boulders were extracted, and, in part, the dismantled lime-kilns themselves, of which three still remain intact. The fire-reddened

stones as Russell pointed out are scattered around, and line many of the hollows. The "triple ridge" is where the Delves form a double row. Small limestone boulders beneath the notice of the lime-burners can readily be found, though not by Professor Gregory, in spite of the clear guidance of all his precursors. Even lacking these, however, the black chert, wholly dissimilar in form, size, and structure to the little pellets of chert in the Millstone Grit, should have warned him off so extravagant a blunder as to put the ice *on the wrong side of the moraine*—an error of which he was guilty in his memoir on the Irish Eskers, and perpetrates again in regard to the Roman Ridge at Lindrick (not Lendrick), near Ripon.

Such a series of blunders, errors of observation, errors of interpretation, should, I think, make every geologist hesitate to accept Professor Gregory's judgment upon any question in Glacial Geology at least.

I have on a previous occasion had to call attention to Professor Gregory's mis-use of quotation—here we have his inaccuracy illustrated in another form: he pronounces his preference for the description by Carvill Lewis over that by Green (meaning Russell), yet he shows himself ignorant of the most vital and significant facts in the record. When did Professor Gregory read these documents, and why has he made no use of their contents? Are the references to them mere embellishments? These are questions that naturally arise. I make no comment upon the discussion upon the "Low-level Kames of the Aire Valley", merely remarking that anyone who desires to obtain a clear and comprehensive account of the Glacial phenomena of the district with maps of the moraines, and evidence of the moraine-like phenomena, will find it in the paper by Jowett and Muff already quoted, but they will not find it in Professor Gregory's paper.

I turn to another section, namely, that on "Eskers in North Yorkshire and near York", with some reluctance, as my object is not to vindicate my own work but to criticize Professor Gregory's, and to enforce the warning that his peculiar methods in the field and in the study do not conduce to a correct apprehension of the problems. The phenomena to be explained are the two great crescentic ridges of drift, about 4 or 5 miles apart, which span the Vale of York in fairly close parallelism, the City of York standing about the middle of the northern arc.

The first suggestion that these were the terminal moraines of a great glacier appears to have been made by Dakyns,[1] though his meaning is not clearly expressed, but Carvill Lewis gave unambiguous expression to this view at the Manchester meeting of the British Association in 1887, from which occasion I date my interest in Glacial Geology.

Already in 1881 Mr. J. E. Clark (the J. *F.* Clark of Professor Gregory) had given a most valuable and careful account of the

[1] *Q.J.G.S.*, xxviii, p. 387.

sections exposed in the construction of the great railway station at York: he has very generously placed all his notebooks in my hands.

The Memoir of the Geological Survey, published in 1884, described the ridges, and gave excellent diagrams exhibiting their structure but significantly refrained from speculation on the subject of their mode of origin, which was said to be part of a very large subject and not to be discussed in a local memoir. My own contribution appeared in 1894 (not 1893 as stated by Professor Gregory). Fox Strangways [1] in 1895 added many details and supported the morainic theory, which he applied also to other areas of Yorkshire.

Except brief summaries by myself in the *Victoria History of Yorkshire* and the *Handbuch der Regionalen Geologie*, the only addition to the knowledge of these ridges prior to Professor Gregory's is the brief allusion to them by Professor Bonney in his Presidential Address to the British Association, a few isolated observations upon a borehole at Escrick, and references to the laminated mud overlying the mounds near York.

Let us now see what Professor Gregory has to say. "Two curved bands of glacial sands and gravels occur in this part of Yorkshire. . . . A second curved band of boulder clay capped by sand and gravel is marked on the Geol. Surv. Map (Sh. 93 S.E.), passing 5 miles south of York through Catton to Escrick and Stillingfleet (35 feet)." It is difficult to attach any other meaning to the figures "35 feet" than that this is the height of the ridge above Ordnance Datum. In fact, the village does not stand on the ridge, which here ranges from 85·9 down to 50 feet, where it is truncated by the valley of the River Ouse, but at one intermediate point it falls to 48 feet. Professor Gregory's figures are grossly misleading.

Of the southern ridge Professor Gregory remarks "Its height is about 30 feet above the adjacent plain; its slopes are gentle, and it shows neither the humpiness characteristic of moraines, nor the steep sides of kames. I saw on it no large erratics. It appears to be a rise left by denudation. This view agrees with that of Professor Bonney . . . 'the so-called moraines near York . . . do not, in my opinion, show any important difference from ordinary hills of sands and gravels, and their materials are wholly unlike those of indubitable moraines that I have either seen or studied in photographs.'"

Before coming to any decision regarding these remarkable ridges one would have expected a geologist to make himself familiar with their form, constitution, and relation to the adjacent deposits, especially as he comments on the fact that the published information deals "rather with the distribution of the drifts than with their composition and structure". To supply the omission Professor

[1] *Proc. Y. G. and P. Soc.*, vol. xiii, p. 18 *et seq.*

Gregory has recently revisited the district. What has he new to say of the crescents? The one passing through York is included in the general description as "Glacial sands and gravels" without qualification, yet Dakyns, Clark, Fox Strangways, and Carvill Lewis describe it as consisting principally of boulder-clay ranging up to a thickness of 70 feet; and there has been for many years in the railway cutting that completely intersects the ridge near Holtby an exposure showing nothing but boulder-clay, with a few wisps of sand.

The description of the southern ridge Professor Gregory, apparently on second thoughts, qualifies by the sentence quoted above, though without any confirmation from his own observation. In fact, this ridge, where traversed by a light railway near Wheldrake, showed an extraordinary tangle of boulder-clay with loops and pockets of sand and gravel, and a bore-hole at a farm-house on the summit of the ridge proved exactly 100 feet of boulder-clay. A similar appearance near Escrick Station is described by Dr. Parsons.

The description of the contours of the southern ridge are very misleadingly described by the omission of any reference to the fact that, like its northern fellow, it protrudes through a great mantle of so-called "Warp" clay, and thus both its height and the contour of its flanks are concealed.

The agency which, according to Professor Gregory, produced this pair of parallel crescents is discoverable only by the implication of his remark that the southern one "appears to be a rise left by denudation", leaving it to be assumed that the northern one of similar structure is also residual.

How this denudation was effected and by what agency, no suggestion is vouchsafed. Professor Bonney's naive comparison with "ordinary hills of sand and gravel" is no more helpful. One might as well dismiss the geology of the Matterhorn with the remark that it was "an ordinary mountain of schists".

Professor Gregory derives some comfort, apparently, from the fact that Mr. J. E. Clark "favours their [the drifts] deposition by floating ice", but that solitary piece of consolation should have been put in the past tense, for Mr. Clark's candid and alert mind promptly recognized the applicability of the morainic hypothesis, and he frankly admitted twenty-five years ago that this explanation was preferable, so Professor Gregory is left with but a single supporter.

I am well aware that scientific questions are not settled by a count of votes, but the competency and experience of the voters should carry some weight, and I can cite among upholders of Dakyns' morainic hypothesis, apart from British observers not a a few, five American geologists, four of whom could each be credited with the mapping of hundreds of miles of moraine in the North American continent; they are Lewis, Wright, Upham, Leverett, and W. M. Davis.

The long ridge of gravel which runs from moraine to moraine is the ostensible object of Professor Gregory's research, and whether it should be styled "kame", "esker", or be fobbed off with a mere "glacieluvial", matters much less than that we should have a clear and unsophisticated account of its structure, form, and relations. As to structure, I have little to say, beyond the remark that my observations of gravel-pits upon the crown *and flanks* of the ridge do not confirm Professor Gregory's description of it as "part of a thin sheet". But when we come to the form the case is altered. Professor Gregory declares that "it does not form a conspicuous ridge; the slopes are very gentle". In proof of this assertion, he chooses one of the lowest points along the ridge, and recites the Ordnance levels along a road going out into the marshy plain. He was, perhaps, unaware that like the moraines, the greater part of this ridge is buried beneath the great sheet of Warp-clay, and that probably not more than 5 feet of the ridge protrudes at the point chosen. I could select profiles showing an emergent ridge of 25 feet or more. Even if it were true, which I deny, that the gravels and sands of the ridge are horizontally bedded, the onus would still rest upon Professor Gregory to make good his assertion that they are part of a thin sheet, and to show by what agency the very eclectic erosion could have been effected.

I have criticized three out of the many examples discussed by Professor Gregory, and I find in the first a perfectly amazing lack of observation, even when the work of others clearly indicated the objects to be observed. Coupled with this a confidence in generalization only equalled by its flagrant conflict with the facts.

In the second case of the York and Escrick moraines, the descriptions of their constituent materials ignores the detailed work of the very authors cited, which perhaps is a venial offence, as Professor Gregory contradicts himself, first describing the two ridges as consisting of sand and gravel, and later making one of them to consist of boulder-clay, capped by sand and gravel.

In every reference to the form of these ridges there are grave misstatements, and the suggested origin of the southern ridge as "a rise left by denudation" is perfectly futile in the absence of any explanation of the agency by which the crescent was produced; moreover, the reader is left wholly uninformed as to the York ridge, unless it, too, is a rise left by denudation, in which case the question of the agent becomes still more urgent.

After this demonstration of Professor Gregory's inability to interpret even the most patent and obvious phenomena in the field, and his, I hope, unparalleled carelessness in quotation, I for one, grateful as I am to him for many ingenious and fruitful suggestions, must refuse to accept without corroboration of more deliberate workers either his facts or his inferences.

Dolomitization in the Carboniferous Limestone of the Midlands.

By L. M. Parsons, M.Sc., D.I.C., F.G.S.

(WITH PLATE VI.)

(*Concluded from p.* 63.)

IV. The D_1 Dolomitic Limestones of Gratton and Long Dale.

The middle portion of the D_1 beds seen in the Gratton Dale section consists of about 630 feet of dark dolomitic limestones, which appear to be confined to a definite horizon in the sequence. The impression one at first receives is that here are definitely bedded dolomites probably of contemporaneous origin, and this material has already been referred to as a thick bed of dolomite.[1] Working

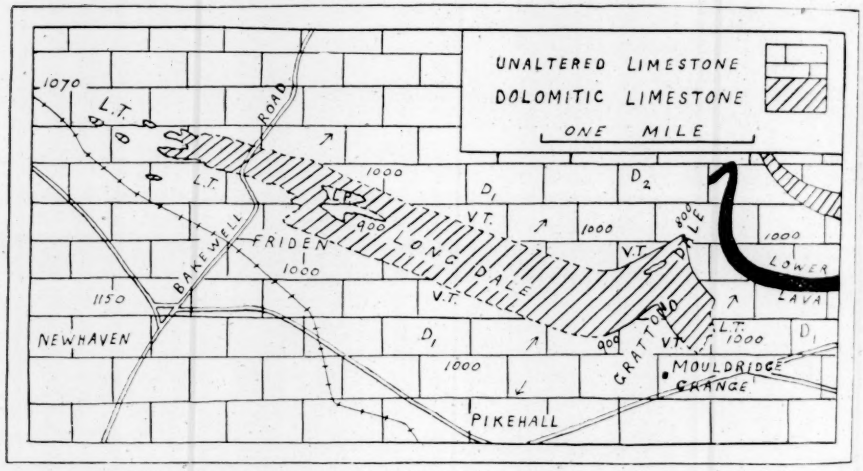


FIG. 3.—Map illustrating dolomitization in Gratton Dale and Long Dale.

northwards down the dale, i.e. ascending the sequence, one finds that the vertical passage from normal limestone into dolomitic material above is everywhere obscured. Similarly the upper limit of the dolomitized beds is covered, so that it is impossible to say whether the metasomatism abruptly ceases with a certain bed or dies out gradually in the higher strata. In the affected part of the sequence the dolomitization appears persistent in Gratton Dale, and at a few places only have I found lateral transitions, one or two examples on either side of the dale. The most marked transition is on the western side, towards the upper part of the altered material. Here light-coloured limestones are seen to pass laterally within a few yards into darker dolomitic material, with which it contrasts. Careful examination shows that these limestones on both sides

[1] Dr. H. H. Bemrose, *Proc. Geol. Assoc.*, vol. xxvi, 1915.

of the Dale are really transitions, and are not interbedded with dolomite, a matter of considerable significance. North-westwards the dolomitization extends for some distance up Long Dale which joins Gratton Dale at right angles.

Throughout Long Dale, which extends parallel with the strike, I have been unable to see any vertical junction between the limestones below and the dolomite above. The vertical change, however, must be fairly abrupt, since for some distance the beds on the northern side are dolomitic while those on the southern side are normal limestones. The actual lower boundary of the metasomatism here lies under the grass-grown bed of the valley. About a mile up Long Dale the valley swerves a little northwards, and the dolomitization is then seen on both sides, indicating that the metasomatism definitely persists along certain beds since the dip of the strata remains the same. Westwards, as Friden is approached, lumps of limestone and dolomite are found mixed in scree material; while still further the dolomitization rapidly becomes less persistent, and good examples of transitions into limestone occur on both sides of the valley. The actual passages from dolomite into limestone are seen to be abrupt. Kernels of limestone, often several feet in width, occur surrounded by dolomitic material. Before the Bakewell road is reached the lower beds have all become normal limestones, and beyond this road the upper dolomitized beds become patchy, and eventually kernels of dolomite in limestone and larger isolated masses, as at Parsley Hay, are all that appears to represent the massive dolomites of Gratton, less than 3 miles distant. Westwards, the field evidences are quite definitely in favour of subsequent dolomitization. Eastwards the matter is less satisfactory. The hilltops above Gratton Dale, a little east of Mouldridge Grange, are overgrown, and I have been unable to trace the dolomitization further. This part of the sequence could, of course, be faulted out, but there is no evidence of this.

The whole of the dolomitized beds pass more or less abruptly into limestone in an easterly direction, and this abrupt passage has its parallel in the sudden transition of Harborough dolomite into the limestone of Middleton Moor, described in the next section. An important feature that must not be overlooked is the fact that in these D_1 beds the dolomitization is extensive and persistent only in the valleys. Eastwards and westwards where the dales give place to higher ground the metasomatism dies out. This is the converse of the dolomitization on the heights near Matlock.

In their structural and mineralogical features the D_1 dolomitic limestones of Gratton resemble, in many ways, the material of Winster. Thus considerable obliteration of bedding planes has occurred; vesicular weathering is a pronounced feature, and pseudo-brecciation is absent. On the other hand, there are well-marked differences between the materials of the two horizons. That at Long Dale is frequently exceptionally coarse in texture;

cavities and vesicular structures are often on a more pronounced scale, and the material being of D_1 age is comparatively unfossiliferous.

Microscopic sections typically exhibit grains and crystals generally rather allotriomorphic and of varying size, mixed with residual calcite. Generally the grain is much coarser than that of the Winster or Matlock material, typical dimensions being a minimum diameter of ·09 mm. and a maximum diameter of ·9 mm, a common size being ·4 mm. A certain amount of limonite is interstitial, but I have not found any zonal growths of iron oxide. Chert is absent from this part of the sequence. There are no selective phenomena.

Thin sections of the transition limestones show that the original material, if similar, consisted of fine-grained foraminiferal limestone (see Pl. VI, Fig. 1), containing a moderate amount of recrystallized calcite, though the recrystallization might have occurred at a later date. I have not found alternating zonal growths of calcite and dolomite suggesting that calcification and dolomitization may have occurred simultaneously. Analyses show that the bulk of the altered material consists of dolomitic limestone having on an average about 15 per cent of magnesium carbonate, though sometimes the proportion is as low as 8 or 9 per cent. Specific gravity and porosity also vary a good deal, many of the vesicular varieties having a porosity as high as 12 or 13 per cent. Considerable leaching must have occurred, though it must be remembered that shrinkage due to molecular change during metasomatism helps in the production of vesicular structures.

The evidences outlined above amply justify the conclusion that the metasomatism is of subsequent origin and produced by magnesian ground waters, but it is difficult to say at what period or periods the alteration took place and in precisely what manner it was brought about. The dolomitization being persistent only in the valleys might suggest that magnesian waters formerly occupying the dales may have reacted only with certain beds on account of some inherent quality rendering those particular beds susceptible to alteration. This is merely a suggestion, and more definite evidence is necessary before it can be accepted as a proved explanation of the dolomitization. The D_1 beds of Gratton prove quite conclusively that subsequent dolomitization can affect certain beds and leave others below and above unaltered. Such differential subsequent dolomitization being possible, caution is necessary with regard to conclusions drawn from apparent interbedding of limestone and dolomite seen in small exposures or restricted areas.

V. The Dolomites between Parwich Moor and Wirksworth.

South of Grange Mill highly dolomitic material is extensively developed in two areas, which appear to have formed originally one large outcrop. The Brassington strike fault has let down the western part of the dolomitized mass, the two portions being

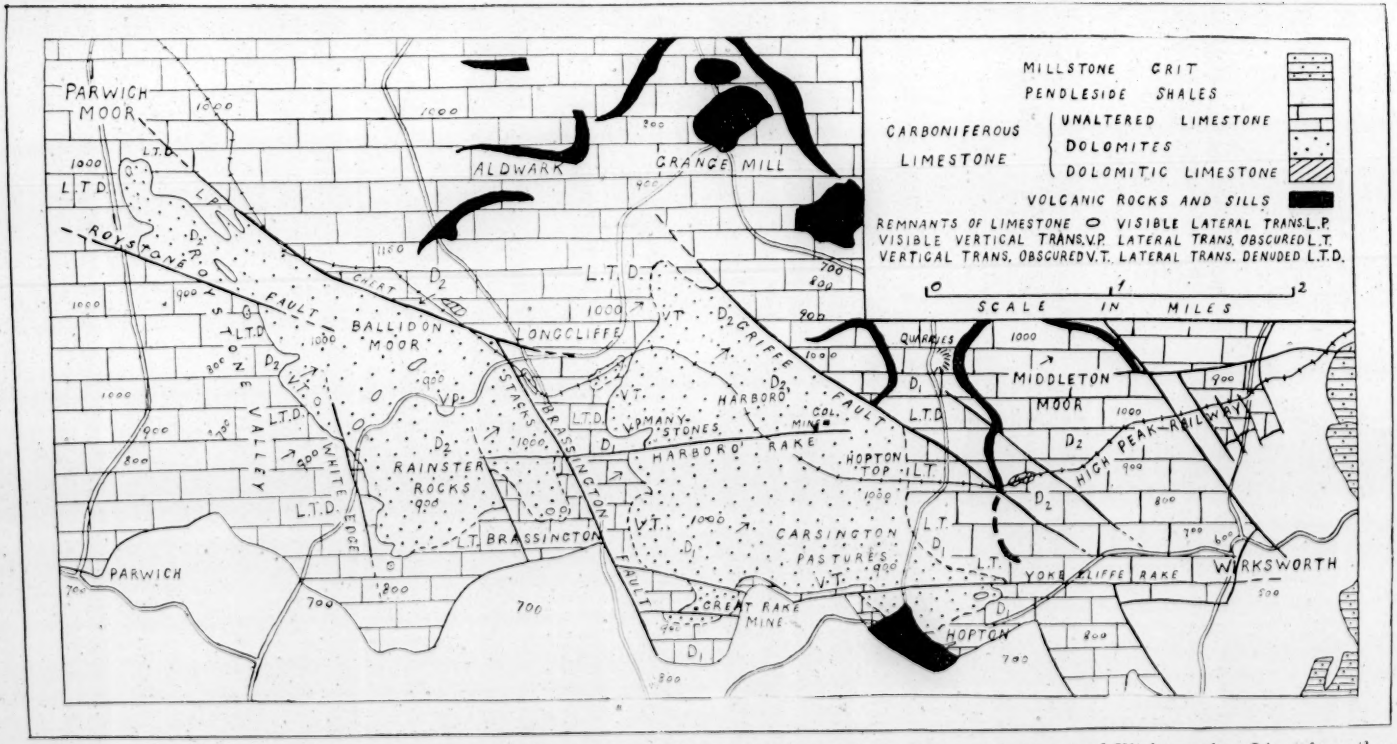


FIG. 4.—Geological map illustrating dolomitization in the Carboniferous Limestone between Parwich Moor and Wirksworth. Lines from the maps of the Geological Survey with tectonic modifications and pseudo-strata of metasomatism by L. M. Parsons.

separated by a narrow belt composed of unaltered limestones of a lower horizon in D_1.

The metasomatism reaches its culmination in the terraced mass known as Harborough Rocks. In this region the dolomitization appears to be characteristic of a definite part of the sequence and has been described as such in one of the earlier Survey Memoirs.[1]

In a later Survey Memoir the opinion is expressed that the dolomitization is not confined to beds of a particular horizon.[2]

Although the dolomitic material of this district exhibits many inherent features similar to those of the rocks of Winster and Matlock, description in a separate section of the paper is justified mainly by differences in horizon and relations between tectonics and field relations.

Field Relations.

Boundaries up and down the sequence.—West of Ballidon Moor, and, again, in the country east of Brassington, where the apparent base of the dolomitic material is brought to the surface by the general dip, there appears to be a sharp line of division between the limestone below and dolomite above. The dolomitization at any particular part of the area so obviously follows the bedding and dip, and is so consistently modified by faulting, that conclusions formed from these prevalent features alone would be decidedly in favour of either primary precipitation or contemporaneous alteration. Whatever may be the origin of the metasomatism, there is no doubt that any part of the field showing limestone below and dolomite above exhibits a definite lowest "bed" of dolomite which may be conveniently termed the "*basal dolomite*". Whether the basal dolomite of one locality is on the same horizon as the basal dolomite of any other locality or occurs at a different horizon, is a question that must be settled by reference to the faunal characters of the lowest dolomite itself and of the limestone immediately below.

At Hopton, Carsington, and south-east of Brassington, the basal dolomite is in the D_1 part of the sequence and a similar horizon is found in the lowest dolomite near Manystones Quarry, west of Harborough.

In the vicinity of the Griffe Walk, further north, however, the basal dolomite appears to be in D_2 beds. Consequently there is, here, a change in horizon and a fairly steep horizon gradient. In the dolomitic mass faulted down west of Longcliffe, the basal dolomite appears to be mainly in D_2.

Horizon changes are generally so gradual that they are imperceptible at any restricted portion of the field. It is clear that the D_1 portion of the Harborough dolomite has passed laterally into

[1] North Derbyshire, 1887, p. 24.

[2] The Geology of the Northern Part of the Derbyshire Coalfield and Bordering Tracts, 1913.

limestone between Manystones and the region around the Rainster Rocks, less than 1 mile distant.

Faunal evidences prove that the bottom of the basal dolomite in the district as a whole is not a true stratigraphical plane of separation.

Evidences obtained from exposed vertical transitions also tell against the theory of contemporaneous origin. In a field west of Manystones, several yards of the " basal dolomite " are seen resting on unaltered limestone. The junction, though sharply marked, does not conform accurately to the bedding. At certain places irregular metasomatic patches invade the limestone below. Thin sections of the limestone in contact with dolomite do not show any dolomite rhombohedra, hence the metasomatism, though irregular, ceases abruptly.

The small exposure near the roadway north of the Rainster Rocks shows a few feet of dolomite sharply separated from limestone below. Thin sections of the limestone in contact with dolomite show that here dolomitization, imperceptible megascopically, has affected the limestone on a minute scale. Well-marked dolomite rhombohedra occur in both organisms and matrix, the latter being partly recrystallized (Pl. 2, Fig. 2). The degree of magnesiation in the limestone immediately below the basal dolomite is thus varied in the area, and ranges from megascopically apparent epiphyses to the entire absence of magnesium carbonate as shown by microscopical sections and chemical analyses. In the workings of the Golconda Mine [1] the basal dolomite is persistently separated from the limestone below by a sharp boundary which conforms to the bedding.

A striking feature which lessens the value of evidence from the vertical passage seen in these workings is the occurrence of a " wayboard " of clay separating the dolomite and limestone. The inference that the limestone below may have been protected by this clay from metasomatism appears legitimate. In a cutting at Longcliffe station and in quarries near Longcliffe pseudo-interbedding effects similar to those of the exposure near Manystones are seen.

The higher vertical transition of the upper dolomites into limestone is not seen anywhere in the whole district between Roystone and Wirksworth. It is to be regretted that the passage material has either been removed by denudation as at Harborough and Rainster, or has been let down by faulting as at Griffe Wood and north-west of Longcliffe. Towards Wirksworth, where the sequence ascends into higher D_2, lateral transition has occurred.

Lateral Boundaries.—The eastern boundary of the Harborough and Carsington dolomitic mass is partly faulted and partly of the nature of abrupt lateral transition into limestone. In the region of the Griffe Wood a sharp straight line with dolomite on one side and limestone on the other marks the position of the Griffe Fault. I have not found any traces of magnesiation in the limestone thus

[1] For facilities to examine these workings I am indebted to the courtesy of the manager, Mr. E. Weightman.

brought abruptly against dolomite. Thin sections show organic structures in a matrix mostly non-recrystallized, and no rhombohedra are present. It is quite clear from field and petrological evidences that this fault has no relation to the origin of the metasomatism. Apart from all other evidences, the moderate throw of this fault as shown by the presence of a D_2 fauna in the higher Harborough beds is fatal to any conception that the massive dolomites of Harborough and Rainster might be a continuation of the thick middle D_1 dolomitic series of Gratton Dale, described in Section IV. East of the Hopton roadway, the Hoptonwood Quarries exhibit a considerable vertical section embracing a large portion of the D_1 sequence below the lava while lower D_2 beds above the lava are seen on Middleton Moor. The shaft of the old Snake Mine pierces other beds lower in D_1, and a table of the strata seen there is given in one of the Survey Memoirs.[1] No dolomitization whatever is found in any of the material seen in the Snake Mine, in the Hoptonwood Quarries, or on Middleton Moor. It is evident that the dolomitized beds around Harborough have all passed more or less abruptly into normal limestones somewhere between the position of the Griffe Fault and the Hoptonwood Quarries, a distance less than three-quarters of a mile. Near the High Peak Railway, and further southwards visible exposures indicate that the dolomitized D_1 beds here pass rapidly into limestone though the actual lateral contacts are obscured. Along the southern boundary from Hopton to the Great Rake Mine, the dolomite and the underlying limestones have been faulted down to the south. In the absence of borings it is impossible to say how far southwards the dolomitization extends. The faults near the Great Rake Mine have produced lateral shifting of the dolomite pseudo-strata. The junction of dolomite and limestone is again quite distinct and along straight lines. The western boundary of the dolomite from Griffe Walk to the southern extremity near the Great Rake is a weathered termination along the strike, the pseudo-strata being modified at one or two places by dip faulting.

In the mass west of the Brassington Fault, certain dolomitized D_2 beds extend westwards for about 2 miles. In the vicinity of the Rainster Rocks another strike fault is indicated by a straight line of demarkation between dolomite on the west and limestone on the east, while the Harborough Rake produces a well-marked lateral shift in the dolomitic material. Behind Brassington Church are several remnants of limestone in dolomite. Other large remnants of limestone occur west of the Rainster Rocks, and indicate transition in some of the lower dolomites. Owing to these transitions and the White Edge fault, the dolomitization in the Roystone Valley is restricted to the hill-tops along the eastern side, until an extensive dip fault lets the material down, the dolomite then occurring on both sides of the valley. The Roystone fault is one of the most clearly marked in the

[1] North Derbyshire, 1887.

district, and shows apparently thick-bedded dolomite against thin-bedded white limestones.

It is evident that the transition material formerly on the western hill-tops has been denuded. South of the fault dolomitic stacks surrounded by limestone occur on the eastern side of the valley. A little north of the fault lateral transition of some of the dolomitized beds gives the appearance of interbedding of dolomite and limestone. Still higher up the valley more lateral transitions occur on the eastern side, and extensive dolomitization finally dies out just beyond the Roystone Rocks near the roadway from Parwich to Pike Hall.

The northern boundary of the Rainster mass is certainly faulted; limestones with chert are brought against dolomite without chert, and the direction of the dip is different.

In the whole district from Hopton to Roystone the persistent modification of the dolomitic pseudo-strata by the faults is a feature of considerable significance. If the dolomitization were of the type in which faulting had been a factor, it is inconceivable that such a large majority of the faults in the district would show limestones one side of each fault plane and dolomite on the other. It is quite definite that the dolomitization must have occurred prior to the dislocations and is independent of them. The metasomatism is of a subsequent type, but of great antiquity, and probably occurred soon after the Carboniferous Limestone was formed.

With regard to evidences connected with the relation between faulting and dolomitization, certain features may be summarized briefly:—

In the case of primary, or contemporaneous, or subsequent dolomitization which occurred prior to faulting:—

(1) If the throw of a fault is sufficient a "bed" of dolomite is usually against a bed of limestone, and the faulted junction is a sharp line of demarkation.

(2) With thick dolomites a fault of small throw may produce dolomite against dolomite.

(3) The outcrops or pseudo-strata are affected by faulting in the usual ways.

(4) Megascopic crystals of dolomite are not usually found in fault planes and cavities. Should such crystals occur, complex or compound dolomitization may be indicated.

In cases of subsequent dolomitization occurring after faulting, particularly alteration of the "vein" type:—

(1) The beds on both sides of the fault are usually affected though those on one side may be more affected than those on the other owing to differences of texture, etc. The line of fault is typically not a sharp line of demarkation.

(2) Dolomitization is more marked in the immediate vicinity of the fault.

(3) The outcrop does not resemble the outcrop of a bedded deposit.

(4) Crystals of dolomite frequently occur in the fault plane and in adjacent cavities.

Inherent Structural and Mineralogical Features.

Many of the structural characters of the material between Hopton and Roystone are very similar to those of the dolomitic limestones around Winster, hence it will suffice if features common to the material of both districts are enumerated and a few notes added.

The common features include :—

Megascopic.—Welding of beds and consequent obliteration of bedding, enlargement of joints, shrinkage, dolomitic stacks and vesicular (differential) weathering.

Microscopic.—The general tendency to allotriomorphism and considerable variation in size of grain (see Pl. VI, Fig. 3), dusky inclusions, interstitial limonite frequently, zonal inclusions of limonite occasionally, and inconclusive " selective " features. (See Pl. VI, Fig. 4.)

On the other hand, the Harborough and Rainster material differs from that of Winster in containing no chert, there is no pseudo-brecciation at all, and in the absence of the lava which dies out near the Griffe Fault, there is no question of metamorphic effects. Obliteration of bedding is prevalent throughout the whole area, and is nowhere better marked than at the Roystone fault. Stacks and pinnacles of dolomite are more extensively developed than in the Winster area, the Roystone Rocks and Rainster Rocks exhibiting this feature in a striking manner. Vesicular weathering is almost universal.

Variation in size of grain is indicated by the following figures obtained from typical sections :—

SIZE OF GRAIN IN DOLOMITES BETWEEN PARWICK AND WIRKSWORTH.

Locality.	*Minimum.*	*Maximum.*	*Common Size.*
	mm.	*mm.*	*mm.*
Harborough .	0·1	0·44	0·2
Harborough .	0·07	0·3	0·15
Manystones .	0·14	1·0	0·6
Manystones .	0·12	0·8	0·4
Carsington Pastures	0·1	0·5	0·3
Longcliffe Stacks .	0·09	0·4	0·25
Rainster Rocks .	0·09	0·45	0·25
Limestone below Rainster Rocks	Fairly uniform size.		0·6

The large idiomorphic crystals in the limestone immediately below the " basal " dolomite of the Rainster Rocks contrast strongly with the allotriomorphic grains in typical material of Harborough, Carsington Pastures, etc. The same mode of magnesiation appears to have produced contrasting results which must have been

determined by other inherent factors as suggested above (cf. Figs. 2 and 3, Pl. VI).

Zonal inclusions of limonite are uncommon, but some of the Harborough dolomite exhibits features very similar to those of the Complex-subsequent D_2 dolomitic material of Gratton Dale. Fig. 4, Pl. VI shows coral structures (*Lithostrotion*) replaced by dolomite free from zonal limonite inclusions, but the matrix mostly contains dense zonal growths of limonite. (Compare with Fig. 3, Pl. IV.) Recrystallized calcite occurs within the spaces between the coral septa. Dolomitization at two different periods is indicated. "Selective" features are varied and contradictory. In examples like that just mentioned, both coral and matrix are almost completely dolomitized, but with dolomite of different types, presumably of different period. In other cases corals are partly in calcite and partly in dolomite, while the matrix is mostly dolomitized. The limestone below the Rainster Rocks shows rhombohedra scattered indiscriminately through both matrix and organic structures.

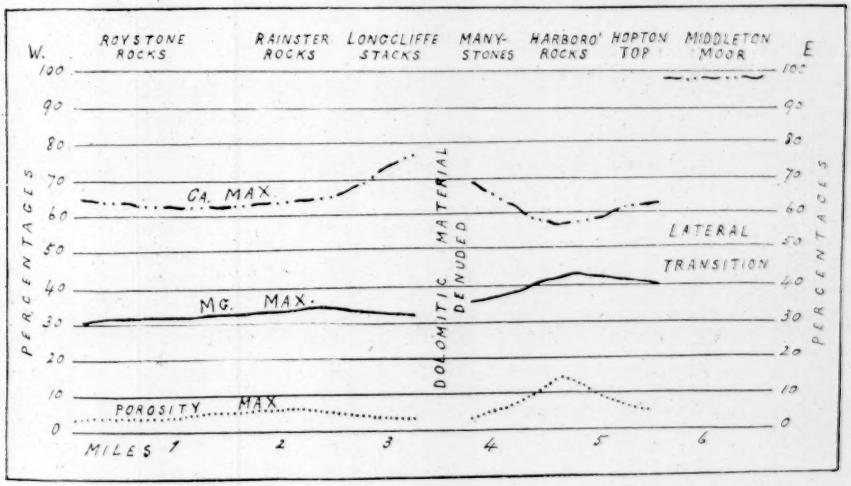


FIG. 5.—Graphs illustrating variation in chemical composition and porosity of the dolomites between Parwich Moor and Wirksworth.

THE PRESENCE AND CONDITION OF FOSSILS.

The general condition of organic remains, and the varied nature of "selective" phenomena so closely agrees with the corresponding features found in the material of Winster and Matlock that the remarks made in Section III equally apply to the material of the Harborough and Rainster dolomites.

CHEMICAL COMPOSITION AND POROSITY.

Chemically, the bulk of the material between Parwich and Wirksworth resembles a true dolomite in having a high proportion of magnesium. Numerous analyses of typical specimens from various

parts of the district show that the dolomitization has been most intense in the immediate neighbourhood of the Harborough Rocks, and that outwards from this centre there is a general fall in the proportion of magnesium southwards towards Carsington and Hopton and westwards towards Roystone.

The dolomitic gradient is, on the whole, moderate, and only at one part of the area, near Longcliffe, have I found a sudden drop in the proportion of magnesium similar to that which occurs in the material near the Wyn Tor, described previously.

In the district as a whole, the chemical variation is not marked in a vertical direction, the lower beds having much the same composition as higher strata at the same locality. The metasomatism ends abruptly at the junction of the "basal dolomite" and the underlying limestones, analyses of the latter showing no magnesium except in the case of the material under the basal dolomite of the Rainster Rocks, which yielded less than 8 per cent of magnesium.

The figures obtained by dividing the percentage of magnesium carbonate by the porosity do not give a constant, and indicate that prior to leaching the dolomitization was not uniform.

TABLE ILLUSTRATING VARIATION IN CHEMICAL COMPOSITION, SPECIFIC GRAVITY, AND POROSITY OF DOLOMITES BETWEEN PARWICH MOOR AND WIRKSWORTH.[1]

Locality.	$CaCO_3$.	$MgCO_3$.	Fe Comp.	Residue.	S.G.	S.G. of Powder.	Porosity.	Per cent of $MgCO_3$ Porosity.
Hopton . . .	62·2	34·3	1·1	2·4	2·46	2·59	5·0	6·8
Hopton . . .	56·8	40·5	0·9	1·8	2·51	2·67	5·9	7·0
Harborough . .	46·4	43·6	3·4	6·6	2·22	2·61	14·9	3·0
Harborough . .	57·1	36·8	1·3	4·8	2·48	2·64	6·1	6·0
Manystones . .	60·5	35·7	1·1	1·7	2·53	2·63	3·8	9·6
Manystones . .	69·3	27·5	0·9	2·3	2·51	2·58	2·7	10·2
Carsington Pastures .	58·7	38·4	1·0	1·9	2·55	2·69	5·2	7·4
Carsington Pastures .	62·3	35·9	0·7	1·1	2·49	2·63	5·3	6·7
Longcliffe Stacks .	64·9	32·6	0·7	1·8	2·53	2·64	4·1	7·9
Longcliffe Stacks .	76·5	20·7	0·6	2·2	2·52	2·61	3·4	6·0
Rainster Rocks . .	63·1	33·8	1·2	1·9	2·54	2·69	6·0	5·5
Roystone Valley .	65·4	31·9	1·1	1·6	2·55	2·71	5·5	5·6

Field relations, certain inherent structures, and chemical composition supply a large balance of evidence indicating that the dolomitization between Parwich and Wirksworth is of a subsequent kind produced by the influence of ground waters. The fact that in the whole of Central Derbyshire the maximum magnesiation is towards the east gives considerable support to the theory of Permian influence. While the magnesian material of the Winster, Matlock, and Harborough districts may have had a common source of origin, there is no proof that the metasomatism in any one of these districts was simultaneous with that in any other.

[1] For considerable help in the chemical part of the work I am indebted to Messrs. A. G. Brighton, C. Jenkins, and H. D. Thomas.

VI.—Summary of Conclusions and Comparison with the Leicestershire Dolomites.

The Carboniferous Limestone of the Midlands exhibits two contrasting types of dolomitization :—

(1) Wholly subsequent in the main limestone mass in Central Derbyshire, and

(2) Almost wholly contemporaneous in the marginal deposits north of the Leicestershire Coalfield.

In neither case is there any extensive development of typical "vein" dolomitization.

In Central Derbyshire :—

(1) Magnesian ground waters appear to have been the agent of metasomatism, but the source of the magnesium is not definitely indicated.

(2) The dolomitization is of more than one period, as shown by certain complex-subsequent types, and as suggested by the relation between the metasomatism and the topography. There is little to indicate the period at which dolomitization took place in the Winster, Gratton Dale, and Matlock districts, but in the case of the widespread alteration in the Harborough area further south, the dolomitization must have occurred prior to the extensive faulting there seen.

(3) It is shown that subsequent dolomitization is capable of affecting certain beds, while others above and below may be left unaffected, hence apparent interbedding is not necessarily a proof of contemporaneous alteration. Different horizons are affected in different parts of the area, the affected horizons in the district as a whole being Middle D_1, top of D_1, lower D_2, and locally near Winster, Upper D_2 ; Upper D_1 beds are affected only around Harborough. Within these portions of the sequence the metasomatism varies horizon, and the surface areas of dolomitization are pseudo-strata.

(4) Extensive dolomitization in Middle D_1 beds is generally restricted to the valleys of Gratton Dale and Long Dale, but that on higher horizons is mostly confined to hill-tops and moors.

(5) On all horizons, lateral transitions into limestone are abrupt, and the transition limestones exhibit feeble or only moderate calcitic recrystallization.

(6) On all horizons the dolomitic material exhibits a general tendency to allotriomorphism, and thus contrasts strongly with some subsequent dolomites of other districts.

(7) Dolomitization has generally produced an increase in size of grain, but in spite of this increase the size of grains and crystals are frequently smaller than those of some contemporaneous dolomites of other areas. Neither allotriomorphism nor size of grain can be accepted as unimpeachable evidence of the mode of magnesiation. Such features appear to be closely related to the original texture and mineralogical constitution of the rock, and to the intensity of the magnesian factor in the agent of metasomatism.

(8) In this area "selective" features are varied and cannot be accepted as a source of evidence of the mode of magnesiation. In the production of such features, the original constitution of the rock is probably the chief factor.

(9) Chemical composition is varied even within small portions of the affected areas, the dolomitic gradients being in some cases steep, in others more gentle. The intensity of magnesiation is greater in the regions around Harborough and Matlock Bath, the magnesian contents generally decreasing southwards and westwards towards Parwich, and north-westwards towards Gratton.

(10) Porosity is intimately related to dolomitization, the *general* connexion being that the greater the degree of magnesiation the higher the porosity. Porosity is due to dolomitic reconstitution of the rock and to post-metasomatic leaching. Pronounced vesicular weathering is a feature associated with subsequent dolomitization.

Bordering the Leicestershire Coalfield :—

(1) The bulk of the sequence consists of some 800 feet of well-bedded contemporaneous dolomites without alternation with limestones. The surface areas of dolomitization are not pseudo-strata. These rocks constitute a shallow-water facies formed during long-continued subsidence.

(2) The horizons affected by this contemporaneous alteration include all of the visible D_1 beds and nearly all of the D_2–$_3$ part of the sequence. These dolomites, therefore, are in Central Derbyshire represented by deposits originally normal limestones, some of which have been subsequently dolomitized. How far northwards from Leicestershire the contemporaneous metasomatism extends is not known, the Carboniferous limestone being obscured by Trias.

(3) Lateral transitions into limestone and many other features found in Central Derbyshire are absent.

(4) The dolomitic material on all horizons affected by contemporaneous alteration is generally allotriomorphic and fine grained.

(5) "Selective" features are absent, matrix and organisms including corals being completely dolomitized.

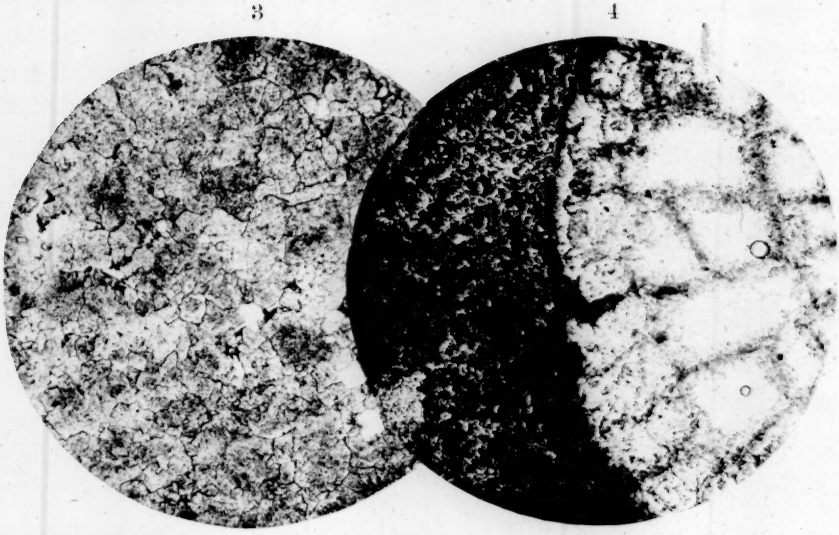
(6) Chemical composition is comparatively uniform, there being slight variation in magnesian contents, but no marked dolomitic gradients similar to those of the Winster or Longcliffe districts.

(7) Porosity is small, evidences of extensive leaching are absent, and there is no vesicular or differential weathering.

(8) A small portion of the sequence towards the top of D_2–$_3$ exhibits a variety of types. Some of these beds exhibit contemporaneous alteration, but have been subsequently dolomitized by waters associated with the Trias. Still higher beds showing very incomplete metasomatism and inconclusive "selective" features cannot definitely be assigned to any particular mode of magnesiation. The highest beds, at Ticknall, are composed of completely dolomitized material apparently of contemporaneous origin.

1 2

3 4



G. S. Sweeting, photomic.

LIMESTONE AND DOLOMITES, DERBYSHIRE.

To face p. 117

I take this opportunity to acknowledge gratefully the financial help afforded by a grant awarded to me by the Government Grant Committee of the Royal Society.

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I am indebted to Mrs. L. M. Parsons for much help with the manuscript, and I acknowledge the companionship of my friend Dr. W. H. Turton, who has frequently accompanied me in the field.

EXPLANATION OF PLATE VI.

FIG.

1.—Transition limestone, D_1 beds, Gratton Dale. × 23. Recrystallized calcite is not common, but occurs occasionally in patches as shown.

2.—Limestone immediately below the "basal" dolomite, Rainster Rocks. × 25. Dolomite rhombohedra with included limonite (not zonal) scattered indiscriminately through matrix and organisms.

3.—Typical dolomite of the Harborough district. × 23. Specimen obtained near Manystones Quarry. Rather allotriomorphic and coarse grained.

4.—Coral in dolomite, Harborough Rocks. × 23. Matrix of dolomite having some zonal inclusions of limonite, coral (right) in dolomite free from such inclusions. Recrystallized calcite in internal spaces. (Cf. No. 3, Plate IV.)

The Carboniferous Limestone Series of West Cumberland.

By Charles Edmonds.

(*Concluded from p.* 83.)

Shallow Water and Lagoon Phases.

In a series which in no part can be described as other than shallow water there are certain passage-beds, speaking of special and varying conditions of deposition, which must be noted. At the very base of the series dolomite-mudstones with ostracods and calcite-mudstones with *Spirorbis*-like annelids, with thin interbedded shales and limestone-bands with a standard marine fauna, denote quiet lagoon conditions with occasional access to open sea. The whole of the Seventh Limestone with its calcite-mudstones, china-stone-limestones and gasteropod-beds, totalling upwards of 150 feet in places, represents generally shallow-water conditions, but there is a remarkable absence of contemporaneous dolomitization in the

beds. Beside this general lagoon-phase of the Seventh Limestone there are other deposits in the series, which tell of still greater restriction of the sea, or even of its temporary exclusion; these occur between the Seventh and Sixth Limestones, between the Sixth and Fifth, between the Fifth and the Fourth, in the middle of the Fourth, between the Third and Second, and between the Second and First. The following are details of (1) the succession at the base, (2) between the Seventh and Sixth Limestones, and (3) at the top of the Sixth Limestone.

SHALLOW WATER PHASE AT THE BASE OF THE SEVENTH LIMESTONE, YEATHOUSE STATION, FRIZINGTON.

Limestone with a standard marine fauna, rests upon :—

		Thickness. ft	in.
16.	Calcareous mudstone[1] with ostracods and small gasteropods: *Nematophyllum minus* McCoy appears	1	6
15.	Black shale		4
14.	Calcareous mudstone with ostracods and small gasteropods	1	0
13.	Calcareous shale with sandy layers		6
12.	Calcareous mudstone with ostracods and fish-teeth fragments	1	0
11.	Black shale or mudstone		6
10.	Calcite-mudstone with conchoidal fracture	1	3
9.	Dark dolomitic shale or mudstone	1	0
8.	Dolomite-mudstone, hematite-stained, with *Bellerophon sp.* and large gasteropods	1	0
7.	Sandstones and shale (with dolomitic bands)	3	6
6.	Thin beds of dolomite-mudstone and calcite-mudstone with thin interlayers of shale (*Spirorbis sp.* and small gasteropods)	6	0
5.	Dolomitized limestone with casts of *Productus* and stray corallites of *Lithostrotion martini* Edw. & H	3	6
4.	Dark shale or mudstone		6
3.	Calcite-mudstone (chinastone-limestone) with *Spirorbis*-like annelids and small gasteropods	1	6
2.	Black shales and thin dolomite-mudstones, 1 to 9 inches thick, with pyritic nodules, in hollows in the bed below	2	0
1.	Basement conglomerate of small crushed quartz-pebbles; rests unconformably upon Skiddaw Slates	2	0

SHALLOW WATER PHASE AT THE TOP OF THE SEVENTH LIMESTONE, TODHOLES OPENCAST, CLEATOR.

	Thickness. ft	in.
Blue-grey limestone with *Spiriferina* cf. *laminosa* McCoy (*Punctospirifer*) in abundance, with *Pugnax pugnus* (Mart.), and *Seminula* cf. *ficoidea* Vaughan	2	0
Black Shale		1
Calcite-mudstone weathering white and "flaking" longitudinally, with *Spirorbis sp.*		6
Black calcareous shale		1½
Dark blue-grey limestone		3
Black shale finely laminated		2½
Dark blue-grey limestone (*Psephodus magnus* McCoy)		7
Black limestone		8

[1] The calcareous mudstones (12, 14, and 16) are differentiated from the "calcite-mudstones" of E. E. L. Dixon in that they do not weather white and have no conchoidal fracture; they have a peculiar texture that can only be described as wood-like. The beds marked "calcite-mudstones" are like those described in the "Gower Paper", pp. 516–17.

	Thickness. ft.	in.
Thin beds of calcite-mudstone containing *Spirorbis*-like annelids alternating with unfossiliferous black shales and dark limestones containing fish-teeth remains and ostracods	1	4
Dark blue-grey limestone	1	0
Black shales finely laminated containing lamellibranchs: *Aviculopecten* cf. *plano-clathratus* McCoy, *Modiola sp.*	4	0
Limestone breccia	2	0
Dark sandy shale	1	0
Sandy "rolls" in shale	1	0
Top of thick dolomitized limestone, with standard marine fauna.		
Total thickness of shallow-water phase	14	9

THE BEDS BETWEEN THE FIFTH AND SIXTH LIMESTONES, STOCKHOW HALL QUARRY, KIRKLAND.

The Fifth Limestone, a massive blue-grey limestone, rests upon:—

	Thickness. ft.
Mottled sandy shale, passing upwards into a fissile micaceous sandstone with plant impressions, "fucoid" markings, and worm-tracks, etc.; ironstone nodules	6
Argillaceous limestone with few macroscopic fossils; some small gasteropods and ostracods	5
Black shale or mudstone with ironstone and calcareous nodules	1
Impure limestone, domolitic, with few fossils (coral fragments and *Productus*)	1
Black finely laminated shale, very fossiliferous; *Chonetes* cf. *hardrensis* (Phill.) and *Ch.* cf. *laquessiana* de Kon. in great abundance. Some layers contain many *Pterinopecten* cf. *dumontianus* McCoy, whilst others are packed with *Leptæna analoga* (Phill.) and *Productus longispinus* Phill., *Fenestella sp.*, and many other fossils	5
Impure limestone with *Lithostrotion junceum* and *Syringopora sp.*	4
Argillaceous limestone with *Psephodus magnus* McCoy and other fish-remains; rests upon the thicker beds of the Sixth Limestone	1

ALGAL BANDS.

Limestones composed partly of material which may be referred with more or less certainty to calcareous algæ occur at several levels in the West Cumberland series, but there are four principal horizons that may be noticed.

The uppermost occurs about midway in the Fourth Limestone, immediately below the limestone with *Saccammina Carteri* Brady. At Postlethwaite's Eskett Quarry, Frizington, where it is best developed, the greater part is a band of porcellanous limestone about 2 to 3 feet thick, with conchoidal fracture and containing hematite-stained spots about 1 inch in diameter. Separating this from the massive standard limestone above is about 3 inches of dark shale with plant impressions, whilst below it is another shale or mudstone, 6 inches thick, underlain by a nodular bed, about 2 feet thick, the nodules of which when broken show red spots like those in the band above. Under the microscope the band consists of masses of dense cloudy calcite with interstitial calcite-mosaic, but in the absence of concentric or tubular structures these masses cannot be referred definitely to algæ.

About 100 feet below this band and still in the Fourth Limestone

is the "Girvanella" Band, which occurs at the base of the Rough Beds, dark-grey limestones in which "pseudo-breccia" structure is excessively developed. At Yeathouse *Girvanella sp.* is found encrusting small fragments of corals, crinoid-stems, etc., and shell-debris in a band of limestone, 2 to 3 feet thick, forming the base of the Rough Beds. The underside of this band has long stick-like concretions attached to it and rests on a 3 inch band of coal-like shale with plant-impressions. Below this is a band, 5 to 8 inches, of dark calcite-mudstone containing *Spirorbis*-like annelids, ostracods and small gasteropods. In this band *Girvanella sp.* appears as unstained, oval, or nearly spherical bodies, 1 inch or more in diameter, whilst in the higher band it is stained with hematite, and is usually smaller and more ellipsoidal.

The higher band is recognizable wherever the horizon is exposed, but the "calcite-mudstone", which is very well developed in the north-eastern portion of the area from Yeathouse onward, is absent from the south-western portion, and is represented at Clints by a shale or mudstone. About 20 feet above the base of the Fourth Limestone is a bed, 3 to 6 feet thick, of mottled shale or mudstone which fills up channels in the limestone below (see p. 82). Where the shale is thinnest, and presumably, where the top of the limestone has not been removed, broad sheets of what appears to be algal limestone occur. On an unweathered surface the band has a landscape-marble-like appearance, dark-grey "tones" of colouring matter alternating with lighter ones in wave-like undulations. It has also the porcellanous appearance of algal limestone. On a weathered surface sections of some of the patches remind one of the thalli of wall-lichens; they have reddish centres, with light blue-grey intermediate zones, and darker zones towards the incurved edges. In other specimens the organisms stand out from the weathered surface, and the "undulations" persist in scimitar-shaped "waves", smoothly rounded crest alternating with sharply angular dip, in some cases for many feet, the average distance from "crest" to "crest" being half an inch. The organism may be referred with some certainty to the calcareous algæ, but has not as yet been identified; the band is well exposed at intervals throughout the district. The fourth band, which is badly exposed, occurs as a nodular bed between the Sixth and the Seventh Limestone. The nodules appear to be similar to the masses in the highest band.

Contemporaneous Pot-holes.

At two or three horizons "pot-holes" or "pitted" limestones occur. The "pot-holes" are of two kinds, the one regular and quasi-cylindrical and the other V-shaped in section. The regular and quasi-cylindrical type occurs at the top of a thick post of limestone (20 feet at Clints and 26 feet at Salter Hall), lying immediately below the limestone with abundance of *Saccammina*

(p. 81). Here the "pot-holes" are roughly cylindrical cavities in the limestone, ranging in depth from 4 to 6 feet with an average diameter of 2 feet throughout the greater part of their depth; the bottom is basin-shaped, whilst the top widens out rapidly to a diameter of 6 to 8 feet. At Clints the cavity is filled with siliceous shale or sandstone, and cavity and surrounding limestone alike are overlain by an even-topped bed of sandy shale, a foot thick, above which is an even bed of micaceous sandstone of about the same thickness. Plant-impressions are abundant in the sandstone. The cavities at other horizons are of various widths and depths. The most notable occur in the white limestones at the base of the Fourth Limestone, which form the passage beds from D_1 to D_2. The cavities are here found occasionally cutting clean through one or two of the limestone beds, and forming a V-shaped "gutter" or channel for some distance, which is filled with mottled shale or mudstone.

The cavities and "pot-holes" are invariably filled with shale, sandstone, or rubbly limestone, and the next bed of limestone above presents as its base a horizontal plane. In many instances pot-holes are less than 6 feet apart.

It is noteworthy that the "pot-holes" and cavities are overlain by sandstones, in which the only organisms found are plants, or by what appear to be algal limestones. For the only theory of their origin that is adequate to explain their size and form is that they are hollows eroded subaerially. They point, in fact, to repeated incidents of emergence of the Carboniferous sea-bottom hereabouts during upper D_1 and lower D_2 times. The existence of true limestone-breccia, lying at intervals in lenticular masses in the mudstone which infils the channels, supports this conclusion.

On the whole, the period was one of depression, that allowed the accumulation of much lime-rock material; but this depression was interrupted by incidents of elevation of the Carboniferous sea-floor, sufficient to bring it to the surface. The "pitted" Limestones described by Mr. E. E. L. Dixon in his Gower paper (p. 490) occur also in our area, and their origin may be similar to the features described above.

Fauna.

The fossils listed in the tables and figures will be deposited in the British Museum of Natural History at South Kensington, as will also the larger collection at present in the possession of the author and solely collected by him, when the listing is completed.

Fossils are fairly abundant in the limestones, but recrystallization has taken place to such an extent, especially in the massive beds of the Fourth Limestone, that the brachiopods, lamellibranchs, and gasteropods are difficult to extract, consequently good specimens are rare. The corals taken from the carbonaceous shales in the First Limestone are in a fine state of preservation, and afford good

Fig. 1.—Vertical Distribution of Rugose Corals in the West Cumberland Limestones.

LIMESTONE	Zaphrentis. Conferticia ennisk illeni	Cyathophyllum ϕ murchisoni. regium.	Carcinophyllum ϕ ϕ sp.	Dibunophyllum ϕ ϕ splendens murchisoni.	Cisiophyllum sublimbricatum	Koninkophyllum ϕ magnificum sp.	Michelinia tenuisepta.	Lithostrotion N. minus phillipsi portlocki irregulare juncteum	Orionastræa ensiter	Lonsdaleia { duplicata. inelinerbiensis. duplicata. dujpicata.	florifermis crassiconus.	florifermis laticlavia.
First												
Second												
Third.												
Fourth												
Fifth												
Sixth												
Seventh												

Note.—Thin continuous lines indicate rarity. Thick continuous lines indicate common occurrence.

material for the study of the structure of many of the members of that ubiquitous class. Almost all genera of rugose corals found in the Lower Carboniferous of other areas in the British Isles are represented, and good specimens are obtainable from practically the whole of the limestones.

Fig. 1 gives the vertical distribution of the principal genera. The abundance of material and mode of vertical distribution greatly facilitate a study of the ontogeny, phylogeny, and the various mutational characteristics of the several members of the order.

Correlation with the Alston Moor Limestones.

Mr. J. D. Kendall in his paper [1] correlates the limestones of our area with the rocks of Alston Moor and Furness as under :—

Alston Moor.	*Whitehaven (= West Cumb.).*	*Furness.*
Yoredale Rocks. Fell Top	First Limestone	
Little	Third Limestone	
Great, Four Fathom, Three Yard	Fourth Limestone	Yoredale Rocks
Five Yard, Scar, Tyne Bottom	Fifth Limestone	
Mountain Limestone	Sixth, Seventh	Thick Limestone
	Red Shales	Red Shales and Limestone

Such a correlation, however, does not suggest itself after an examination of the fossil fauna. Fig. 2 gives the correlation [2] which appears to be most in consonance with the fossils of the two areas. The Fell Top Limestone which Mr. Kendall correlates with the First Limestone has a distinctive fauna that does not find its counterpart in any of our limestones. This fauna is marked by the occurrence of a coral, *Aulina rotiformis* S. Smith, by an abundance of *Dibunophyllum* ψ Vaughan and by certain brachiopods that are characteristic of the highest beds of the Dibunophyllum Zone in the North-West Province and in Derbyshire, such as *Productus aculeatus* Mart. and *Schellwienella radialis* (Phill.). Neither *Aulina rotiformis* nor the brachiopods mentioned have been found in our area. On the other hand, there is a striking similarity between the fauna of the limestone known as the Great Limestone of Alston Moor and Northumberland and that of our First Limestone, as the following list of corals and brachiopods which are common to both shows :—

Dibunophyllum muirheadi Nich. & Thomson.	*Zaphrentis constricta R. G. Carr.*
**Koninckophyllum magnificum* Thomson.	*Chætetes septosa* Flem. [in wide spreading flat sheets]
**Caninia* cf. *sub-ibicina* McCoy.	*Aulophyllum fungites* Flem.

[1] Op. cit.

[2] The approximate scale of this section is 220 feet to 1 inch.

Note.—Thin continuous lines indicate rarity. Thick continuous lines indicate common occurrence.

Lonsdaleia floriformis laticlavia mut. *pachyendothecum* S. Smith.
S. Smith.
Productus giganteus Mart., var.
Productus latissimus J. Sow.
P. pugilis Phill.

* Not known at other horizons.

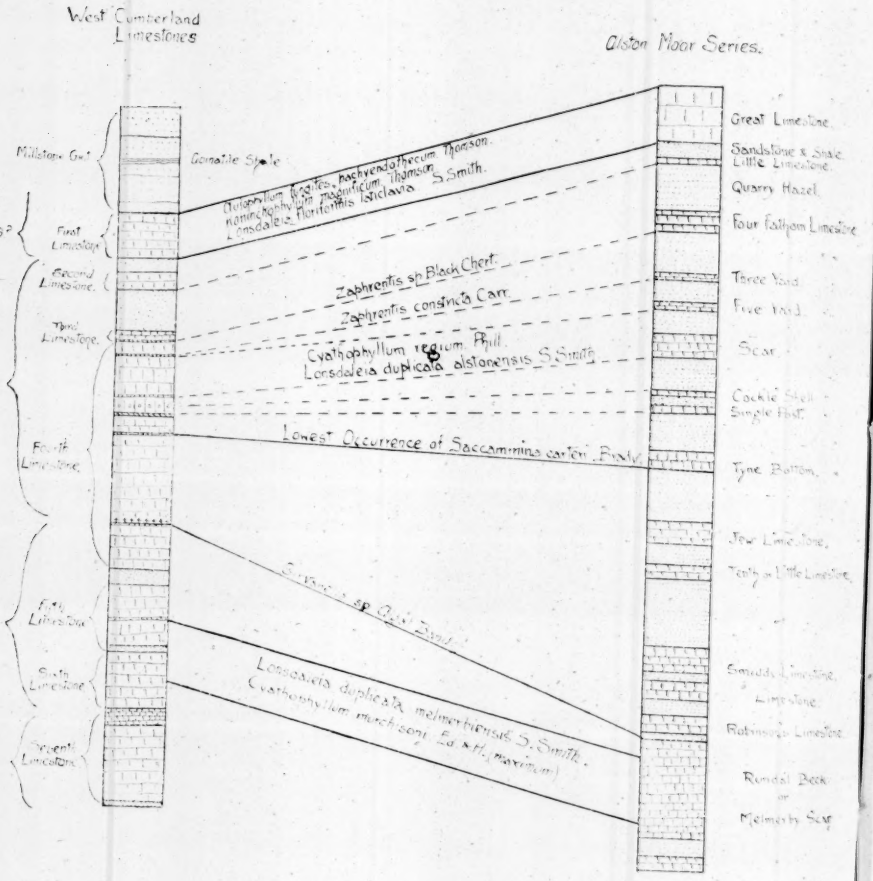


FIG. 2.—Faunal Comparison of the Limestones of West Cumberland with those of the Alston Moor District.

Besides the similarity of their fauna both limestones have a lower massive portion and an upper more thinly-bedded one, in which bedding planes and partings of thin shales are very sinuous but remarkably persistent, individual beds being recognizable at places as far as 10 miles apart. An examination of the beds of the Great Limestone of a district so far removed from our area as Fourstones

Quarry in Northumberland revealed such striking resemblances of bedding, fauna, and general appearance to the First Limestone of West Cumberland as to force the conclusion that they are one and the same bed. The fauna of the smaller limestones below the Great to the Scar Limestone is not distinctive enough to be readily correlated, but black chert is common in beds of both areas and zaphrentids are noticeable corals. The Scar Limestone, which is one of the thicker limestones of the Alston Moor area, and lies about 250 feet below the Great Limestone, has a rich fauna [1] that is comparable with that of a massive bed near the top of the Fourth Limestone, *Lonsdaleia duplicata alstonensis* S. Smith being typical in both Alston Moor and West Cumberland.

Saccammina carteri Brady occurs in three of the beds of the Fourth Limestone; the lowest of these beds is here correlated with the Tyne Bottom Limestone, wherein is the lowest known occurrence of *Saccammina* in the Alston area. Similar faunas obtain.

The Algal Band with *Girvanella sp.* occurring at the base of the "Rough Beds" of the Fourth Limestone marks the next common horizon, it being correlated with the *Girvanella* Band of Garwood, which has been found by him in the lowest Yoredale limestone of the Roman Fell area.[2]

The limestones below present no striking similarities until the lower portion of the Fifth Limestone and the upper portion of the Melmerby Scar limestone are reached, where identical faunas present themselves.[3] These beds are marked by an abundance of the D_1 corals, *Dibunophyllum* θ and *D.* ϕ Vaughan, *Koninckophyllum* θ Vaughan, *Carcinophyllum* θ Vaughan, with a maximum of *Cyathophyllum murchisoni* Edw. & Haime, *Lonsdaleia duplicata melmerbiensis* S. Smith is typical in both areas and found at no other level. The lower portion of the Melmerby Scar limestone can be correlated with the Sixth and Seventh Limestones of our area.[4]

The foregoing correlation suggests:—

(1) That the Carboniferous sea already in possession of the South-West and North-West Provinces converted our district into a lagoon area during Upper Seminula times and slightly before submersion of the Alston area.

(2) That with the beginning of D_2 times the rate of depression in the Alston district was quicker than in West Cumberland, which was farther removed from the source of detrital matter or else partially cut off from it by a land barrier. The detrital deposits kept pace with the rate of submersion and were much thicker towards the north-east, and when for some reason the deposition of detrital matter temporarily ceased it allowed a deposit of limestone to be

[1] Dr. Stanley Smith has given (*Q.J.G.S.*, vol. lxxi, 1916, p. 242) the characteristic fauna of the Scar Limestone.

[2] Garwood's North-West Province paper, p. 482.

[3] Dr. S. Smith, op. cit., pp. 242-3.

[4] Cf. Garwood's North-West Province paper, pp. 481, 539.

laid down almost equal in thickness to the corresponding beds of our area.

(3) That the Fell Top Limestone of the Alston area was deposited in a depression running from Alston Moor to Alnwick long after "Millstone Grit" conditions had succeeded to our First Limestone.

(4) And finally, that during the deposition of the limestones of the upper portion of the series the conditions were so uniform as to allow the accumulation of beds which are recognizable over an area stretching from West Cumberland to the North-East of Northumberland.

Correlation with Other Areas and Zonal Classification.

Fig. 3 gives the correlation of our series with those in several areas in various parts of Britain. I have adopted the table published by Garwood in his North-Western Province paper (p. 547). only substituting more recent names for one or two of the index-corals mentioned by him. As will be seen from Fig. 3 he groups the Great Limestone with D_2. On the other hand, in Figs. 1 and 2, following Dr. Stanley Smith,[1] I have indicated that it may possibly be part of D_3, his correlation being supported by the occurrence in this limestone of a highly specialized sub-species of *Lonsdaleia floriformis* Mart., which he has named *Lonsdaleia floriformis laticlavia*, and which is not known from any lower horizon. The sub-species characteristic of the "Lonsdaleia Beds" of Garwood is evidently from the figure,[2] *Lonsdaleia floriformis* (Mart.) mut. *crassiconus* S. Smith.

Summary.

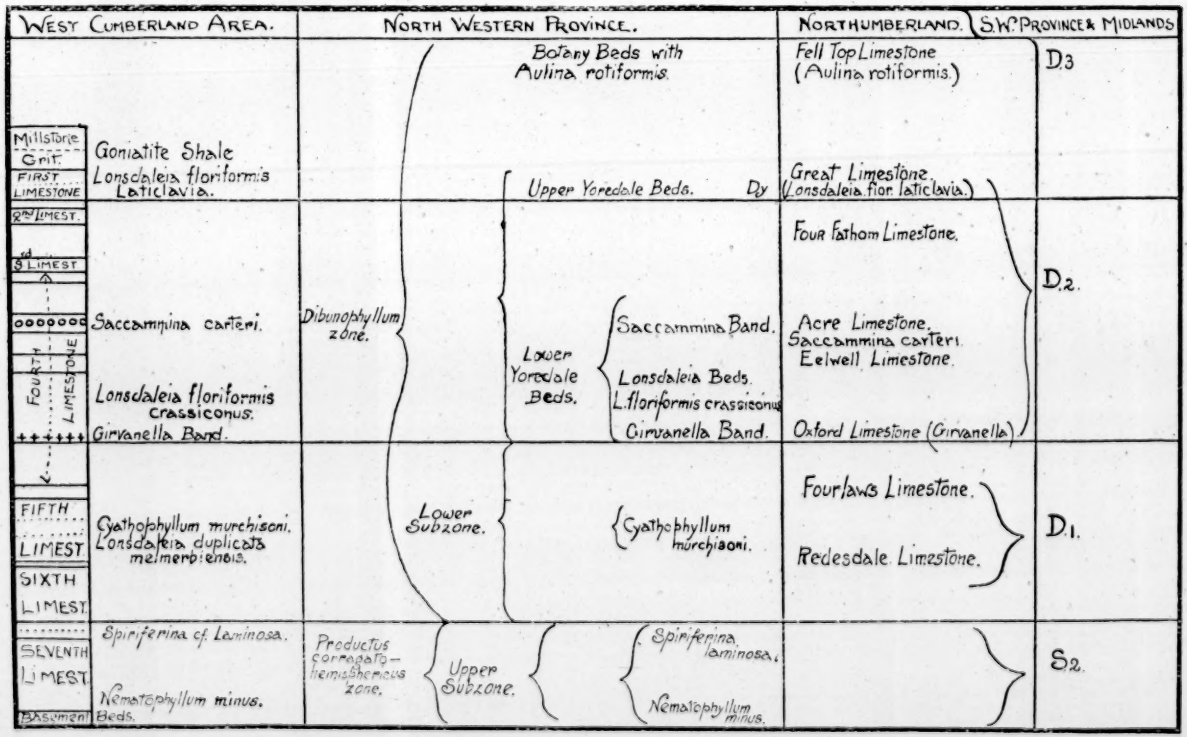
The examination of the fossil fauna, the chief forms of which are shown in Tables I and II and Fig. 1, shows that the beds commence at a high horizon of the *Seminula* Zone and extend to the top of the *Dibunophyllum* Zone. Also, the "life-zones" established by Professor Garwood in his North-Western Province Paper can be readily recognized in our area and the series includes the sequence from the *Nematophyllum minus* sub-zone of the *Productus corrugato-hemisphericus* Zone to the *Dibunophyllum muirheadi* sub-zone of the *Dibunophyllum* Zone. It can further be established that the limestones of our area do not persist up the horizon of the Botany Beds with *Aulina rotiformis* S. Smith. The *Saccammina* Band occurs in our area, but *Saccammina* occurs also in the limestones immediately above and below. The *Girvanella* Band of the North-West Province has been recognized and forms a constant horizon throughout the area. It occurs associated with a calcite-mudstone and never as a nodular bed. Other bands also appear to be algal. The *Spiriferina* cf. *laminosa* Band of Garwood forms a constant horizon between the Seventh and Sixth Limestones.

[1] "The Faunal Succession of the Upper Bernician": *Trans. Nat. Hist. Soc. Northumberland, etc.*, n.s., vol. iii, 1910, p. 591.

[2] E. J. Garwood, *Proc. Geol. Assoc.*, vol. xxvii, 1916, pl. xvii, fig. 1.

Fig. 3.—Correlation...

FIG. 3.—CORRELATION WITH THE ZONES OF THE S.W. AND N.W. PROVINCES AND WITH THE LIMESTONES OF NORTHUMBERLAND.



Earth Movements will be discussed in detail in a forthcoming paper, and are barely mentioned here except that it is perhaps desirable to record that the sequence begins with a shallow-water phase, and that the "Pot-holes" and "Channels" indicate incidents of emergence of the Carboniferous sea-floor.

ACKNOWLEDGMENTS.

To Dr. Stanley Smith I am indebted for help and encouragement received continually over a period of five years, for the revision of the coral lists, and for accompanying me over sections of the area and reviewing my findings. To Mr. Harold Adair, of Keswick, I am also greatly indebted for placing much stratigraphical information, especially of the Egremont portion of the area, at my disposal. Dr. Lee has identified the Bryozoa, Professor Garwood many of the brachiopods, and to these, as also to Professor Reynolds, who arranged for my visiting the classic section in the Avon Gorge, I tender my gratitude. To Dr. W. D. Lang for help at the South Kensington Museum, to Mr. Withers for naming the trilobites, and to Dr. Smith Woodward for examining and naming the fish-teeth and fragments, I am indebted and accord my thanks. My friend and colleague, Mr. William Macdonald, has helped me in many ways. Finally, I have to thank Mr. E. E. L. Dixon, of H.M. Geological Survey. I have been fortunate enough to have had Mr. Dixon with me over part of the sequence, and, needless to say, the presence of such a kindly and enthusiastic worker has lightened the task for me. He has confirmed many of my findings and pointed out to me lithological features which had escaped my attention.

APPENDIX I.

NOTES ON THE RANGE OF CORALS IN THE WEST CUMBERLAND AREA.

ZAPHRENTIS.

Z. enniskilleni, Edw. and Haime, makes its appearance in the Rough Beds of the Fourth Limestone.

Z. constricta, Carruthers, is characteristic of the Third and First Limestones.

CYATHOPHYLLUM.

C. ϕ, Vaughan, enters well up in the Seventh Limestone, reaching its maximum at the top.

C. Murchisoni, Edw. and Haime, enters near the top of the Sixth Limestone, reaching its maximum in the Fifth Limestone, and appearing, more or less abundantly, in all the beds to the top of the Fourth Limestone, where it disappears from the area.

C. regium, Phillips, enters with the last appearance of *C. Murchisoni*, has a short range, but is fairly abundant.

CARCINOPHYLLUM.

C. ϕ, Vaughan, enters fairly low down in the Seventh Limestone.

C. θ, Vaughan, succeeds *C. ϕ* in the Sixth Limestone, reaching its maximum in the Fifth Limestone, and persisting well up into the Fourth Limestone.

C. sp. is a characteristic form near *Carcinophyllum kirsopianum*, Thom., which is abundant in the Junceum Beds.

DIBUNOPHYLLUM.

D. θ, and *D. ϕ*, Vaughan, enter in the Sixth Limestone, reaching their maxima at the base of the Fourth Limestone.

D. θ is abundant in the Rough Beds and persists upwards to the top of the Fourth Limestone.

The highly specialized form *D. splendens*, Nicholson and Thomson, occurs in the Junceum Beds.

D. muirheadi, Nicholson and Thomson, is highly characteristic of the Second and First Limestones.

CLISIOPHYLLUM.

Occurs only in the Junceum Beds and is represented by forms similar to *C. subimbricatum*, Thomson, and *C. keyserlingi*, McCoy.

KONINCKOPHYLLUM.

K. θ, Vaughan, enters in the Sixth Limestone and is abundant in the Fifth Limestone.

The form *K. magnificum*, Thomson and Nicholson, occurs in the Fourth Limestone.

A particular specialized form, *K. sp.*, is characteristic of the First Limestone.

MICHELINIA.

This genus is represented only by a small form, *M. tenuisepta*, McCoy, occurring at one horizon, the Junceum Beds.

LITHOSTROTION.

L. (*hematophyllum*) *minus*, McCoy, occurs in great abundance in the Seventh Limestone.

L. Phillipsi, Edwards and Haime, is abundant near the top of the Seventh Limestone.

A large prismatic form, cf. *L. aranea* Phill., is abundant in the Fifth Limestone.

L. junceum (Flem.) and *L. Portlocki*, Edwards and Haime, range from the Fifth Limestone to the top of the Third Limestone. These species, together with *L. McCoyanum*, Edwards and Haime, are especially abundant in the Junceum Beds.

The Lithostrotions take on a diphyphylloid habit towards the top of the Fourth Limestone, *Diphyphyllum lateseptatum*, McCoy, *D. concinnum*, Lonsdale, and *D. interruptum*, Thomson, being present. There is a remarkable rarity of *Lithostrotion* in the First Limestone, this genus being only represented by a small, straggling, diphyphylloid variety.

Orionastræa ensifer, S. Smith, is particular to one horizon, viz. at the base of the Saccammina Beds.

LONSDALEIA.

The various species and forms of this highly specialized coral have been described by Dr. Stanley Smith,[1] and the forms described by him can be recognized with ease. The vertical distribution in the West Cumberland Limestones agrees with his account of the ontogeny and phylogeny of this genus.

Lons. duplicata melmerbiensis, S. Smith, is abundant in the Fifth Limestone.

Lons. duplicata duplicata, Martin, occurs in the White Beds.

Lons. floriformis (Martin), mutation *crassiconus*, S. Smith, enters in the Rough beds, where it rapidly reaches its maximum and persists to the top of the Fourth Limestone.

Lons. duplicata alstonensis, S. Smith, occurs at the top of the Fourth Limestone.

Lons. floriformis laticlavia, S. Smith, is special to and highly characteristic of the First Limestone.

AULOPHYLLUM.

Aulophyllum makes its first appearance in an immature form in the Rough Beds of the Fourth Limestone.

A. fungites (Fleming), mutation *Cumbriensis*, S. Smith, occurs at the top of the Fourth Limestone.

A. fungites (Flem.), mutation *pachyendothecum*, S. Smith, is characteristic of the First Limestone.

[1] Op. cit.

Chætetes.

Chaetetes septosa, Edwards and Haime, enters in the Seventh Limestone and is fairly abundant throughout the series.

Ch. depressa, Edwards and Haime, occurs in the Fifth Limestone and in wide-spreading sheets in the higher beds of the Fourth Limestone. It is also abundant in the First Limestone.

APPENDIX II.

List of Exposures of West Cumberland Limestones.

First Limestone.

(*a*) At Langhorn, Bigrigg, immediately south of Langhorn Farm, is a fairly large disused quarry in this limestone. About 20 yards west of quarry the limestone can be seen in railway cutting where it is overlain unconformably by Permian breccia.

(*b*) Small quarry behind Orebank House, Bigrigg, overlain by breccia.

(*c*) Small opencast behind Bigrigg Moor houses. Old hematite workings.

(*d*) Large disused quarry at Overend about a quarter of a mile south-east of Hensingham village. The limestone is here overlain by the Millstone Grit.

(*e*) Small disused quarry near Birks Farm, Cleator Moor.

(*f*) Small exposure in railway cutting leading into Kelton Head Quarry, north-east of Rowrah Station.

Sandstones and Shales.

The sandstones and shales separating the First from the Second Limestones are exposed—

(*a*) At Langhorn in disused hematite opencast.

(*b*) At Overend quarry.

(*c*) In railway cutting at Kelton Head Quarry.

Second Limestone.

The Second Limestone is exposed underlying the sandstones and shales at the three places mentioned above.

The Orebank Sandstone.

(*a*) The best exposure of these beds, which consist of a series of sandstones and shales upwards of 70 feet in thickness, occurs in the old hematite opencast between Langhorn Farm and Orepit Cottages.

(*b*) It is badly exposed in railway cutting at Kelton Head.

Third Limestone.

(*a*) Small remnant left on the top of Clints Quarry near limekiln on the Egremont–Whitehaven Road.

(*b*) At Eskett in railway cutting behind Ennerdale Hall.

(*c*) At entrance to Rowrah Hall Quarry.

(*d*) At entrance to Kelton Head Quarry.

Fourth Limestone.

The great extent to which this limestone is used in connexion with the smelting of the hematite ores of the district, accounts for the many large quarries at present being worked in it.

The full sequence of the beds from the "White Beds" at the base to the top of the "Junceum Beds" are exposed in one large and two small quarries at Clints, whilst the "Rough Beds" and some of the beds above are exposed in a series of small knolls in Gillfoot Wood and on the western side of the Egremont–Whitehaven Road.

At Yeathouse Quarry, near Yeathouse Station, Frizington, the beds from the "White Beds" to the base of the "Saccammina Beds" are exposed.

At Eskett Quarry, ¼ mile east of Winder Station, and behind Ennerdale Hall at Rowrah Head, and Rowrah Quarries near Rowrah Station, and at Kelton Head Quarries, the full sequence is exposed, all of the beds being accessible for examination.

A small exposure of the "Rough Beds" occurs near Scalesmoor Farm, Lamplugh.

FIFTH LIMESTONE.

This limestone is fairly well exposed in the district.

A small exposure occurs in the railway cutting leading to Longland's mine, a quarter of a mile south-east of Woodend Station. The upper light-coloured portion of this limestone is shown in the rail cutting leading into Clints Quarry.

It can be seen in Ainsworth's Opencast near Cleator.

A large but inaccessible quarry occurs at Yeathouse.

The best exposure is at Stockhow Hall, half a mile south-west of Kirkland village, where there is a large disused quarry in both portions of this limestone.

A series of small quarries west of Scalesmoor Farm.

SIXTH LIMESTONE.

Badly exposed, there being only two exposures, one a small quarry at Stockhow Hall, the other a small exposure in railway cutting at Yeathouse Quarry.

SEVENTH LIMESTONE.

The base of this limestone and its connexion with the Basement Conglomerate can only be seen at one place in the district, viz. in the railway cutting about 100 yards south-east of Yeathouse Station. There are two good exposures of this limestone proper, one at Frizington Park quarry on the east side of the railway midway between Frizington and Yeathouse Stations, the other at Moosegill Quarry, Wilton, about 2 miles east of Egremont.

Other exposures are at Thistlegill Quarry, 200 yards west of Kirkland village; Todholes Opencast, 100 yards north of St. Mary's R.C. Church, Cleator; a small quarry south of the Co-operative Society's old flour mill, Cleator Moor; and one or two small surface exposures near Scalesmoor Farm, Lamplugh.

Liquid Inclusions in Glass.

By CHARLES E. BENHAM.

IT is well known that the liquid inclusions commonly found in quartz, fluor-spar, and other minerals resemble in some degree those that occur in crystals of sodium chloride, alum, and many salts. Chloride of sodium in particular shows innumerable cavities of varying size, cubical in form (negative crystals), and generally containing an enclosed bubble, especially if heated gently after the crystals are formed. The smaller cavities show Brownian movement of the enclosed bubble in a very striking manner. (See Fig. 1, which gives a diagrammatic view of a salt crystal as seen through the microscope.)

Yet these cavities are evidently so different in origin from those in such a material as quartz that they can hardly be classed as a parallel phenomenon and they throw little light on the actual problem of quartz inclusions, which are highly suggestive of an origin connected with the enclosure within the mineral when molten of aqueous vapour heated under pressure to a degree above the "critical temperature".

Artificial inclusions which approximate perhaps rather more closely to the cavities in minerals may also be obtained in resins by boiling the resin in water, preferably tinted with a dye of some sort or containing an infusion of gamboge particles. The melted

resin envelops thousands of aqueous globules and permanently shuts in these inclusions so that a fragment of such impregnated resin, if afterwards softened by heat and gently pressed between a glass slip and cover-glass, makes a beautiful microscopic object, showing myriads of liquid spherules each containing (when the gamboge is used) a glittering galaxy of ever-moving particles as seen with dark-ground illumination.

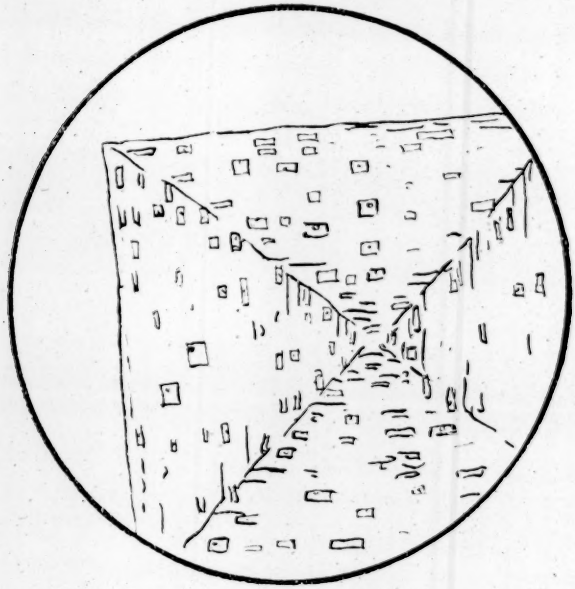


FIG. 1.—Salt crystal with microscopic cavities containing brine and an air bubble, the smallest of which show Brownian movement.

Many of these spherical inclusions, moreover, are not entirely filled with liquid, but show a central air bubble with a diameter about one-third of that of the sphere. Around this is seen a ring of the suspended gamboge particles in rapid movement. The bubbles themselves are generally much too large to show Brownian movement. To ensure their presence the impregnated resin mass should be left a few weeks after the boiling.

The general effect is shown in Fig. 2, which exhibits the various sizes of the spherules, some filled completely with liquid and gamboge particles, others having a central air globule.

An experiment made with a view to imitate much more closely in glass, by artificial means, the liquid inclusions of certain minerals may be worth describing.

A small glass tube, containing water and hermetically sealed, was enclosed in the interior of an unbaked brick, and then submitted (by the kindness of Messrs. H. Everett & Son, of Colchester) to the

usual process of firing in the brick kiln. To avoid any risk of a violent explosion the tube used was only about 3 inches long and $\frac{1}{4}$ in. outside bore. This was nearly filled with water and hermetically sealed in a gas flame at each end. The tube was embedded in the middle of the soft brick so as to ensure a complete sealing in of the liquid contents. The brick, duly marked for identification, was placed amongst the others in the kiln and exposed to the usual period of firing. The idea was to ensure that the glass when molten should come into contact with water vapour above the critical temperature, and that in this way inclusions should be formed in the substance of the glass.

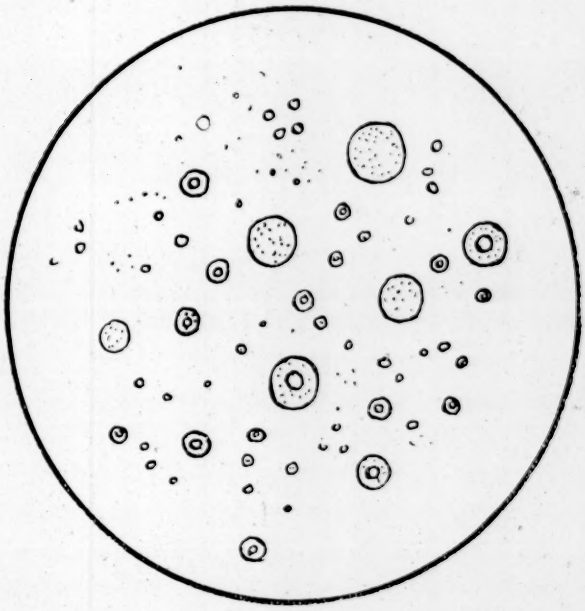


FIG. 2.—Liquid inclusions in resin which had been immersed in boiling water containing suspended gamboge particles. Some of the spherules show a central air bubble, while others are completely filled with the liquid.

The experiment was successful, the glass showing microscopic inclusions, with a bubble of vapour comparable with those found in quartz, affording a possible clue to the formation of inclusions in that mineral.

As will be seen from the drawing (Fig. 3), the glass inclusions were spherical in form. The sketch was made with camera lucida attachment. There were also a good many impurities imprisoned showing as specks and smudgy masses which are not rendered in the drawing as having no special bearing on the experiment, but the fibrous state of much of the glass has been diagrammatically reproduced. This fibrous condition is due to the fact that the heat was

resin envelops thousands of aqueous globules and permanently shuts in these inclusions so that a fragment of such impregnated resin, if afterwards softened by heat and gently pressed between a glass slip and cover-glass, makes a beautiful microscopic object, showing myriads of liquid spherules each containing (when the gamboge is used) a glittering galaxy of ever-moving particles as seen with dark-ground illumination.

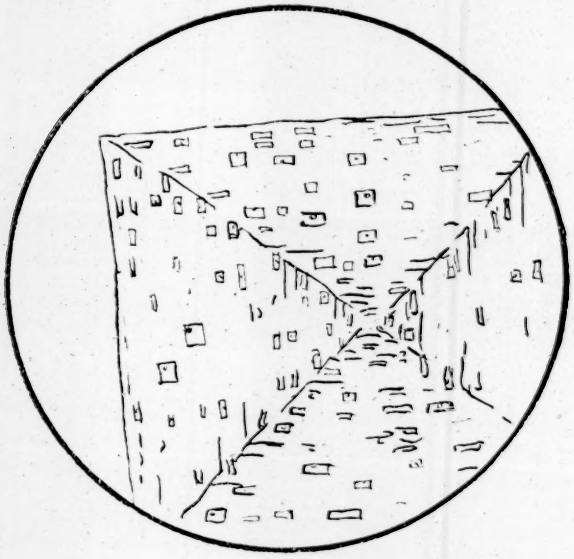


FIG. 1.—Salt crystal with microscopic cavities containing brine and an air bubble, the smallest of which show Brownian movement.

Many of these spherical inclusions, moreover, are not entirely filled with liquid, but show a central air bubble with a diameter about one-third of that of the sphere. Around this is seen a ring of the suspended gamboge particles in rapid movement. The bubbles themselves are generally much too large to show Brownian movement. To ensure their presence the impregnated resin mass should be left a few weeks after the boiling.

The general effect is shown in Fig. 2, which exhibits the various sizes of the spherules, some filled completely with liquid and gamboge particles, others having a central air globule.

An experiment made with a view to imitate much more closely in glass, by artificial means, the liquid inclusions of certain minerals may be worth describing.

A small glass tube, containing water and hermetically sealed, was enclosed in the interior of an unbaked brick, and then submitted (by the kindness of Messrs. H. Everett & Son, of Colchester) to the

usual process of firing in the brick kiln. To avoid any risk of a violent explosion the tube used was only about 3 inches long and $\frac{1}{4}$ in. outside bore. This was nearly filled with water and hermetically sealed in a gas flame at each end. The tube was embedded in the middle of the soft brick so as to ensure a complete sealing in of the liquid contents. The brick, duly marked for identification, was placed amongst the others in the kiln and exposed to the usual period of firing. The idea was to ensure that the glass when molten should come into contact with water vapour above the critical temperature, and that in this way inclusions should be formed in the substance of the glass.

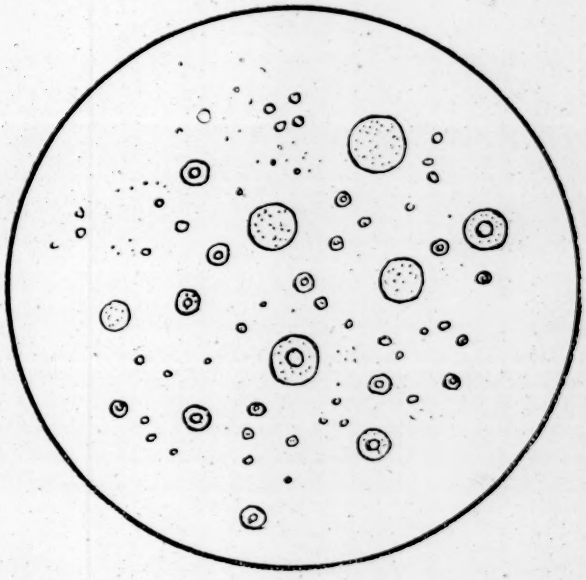


FIG. 2.—Liquid inclusions in resin which had been immersed in boiling water containing suspended gamboge particles. Some of the spherules show a central air bubble, while others are completely filled with the liquid.

The experiment was successful, the glass showing microscopic inclusions, with a bubble of vapour comparable with those found in quartz, affording a possible clue to the formation of inclusions in that mineral.

As will be seen from the drawing (Fig. 3), the glass inclusions were spherical in form. The sketch was made with camera lucida attachment. There were also a good many impurities imprisoned showing as specks and smudgy masses which are not rendered in the drawing as having no special bearing on the experiment, but the fibrous state of much of the glass has been diagrammatically reproduced. This fibrous condition is due to the fact that the heat was

undoubtedly much greater and more prolonged than was actually required for the purposes of the experiment, the temperature of the kiln being not less than 1,200 degrees Cent. The bubbles are too large to show Brownian movement.

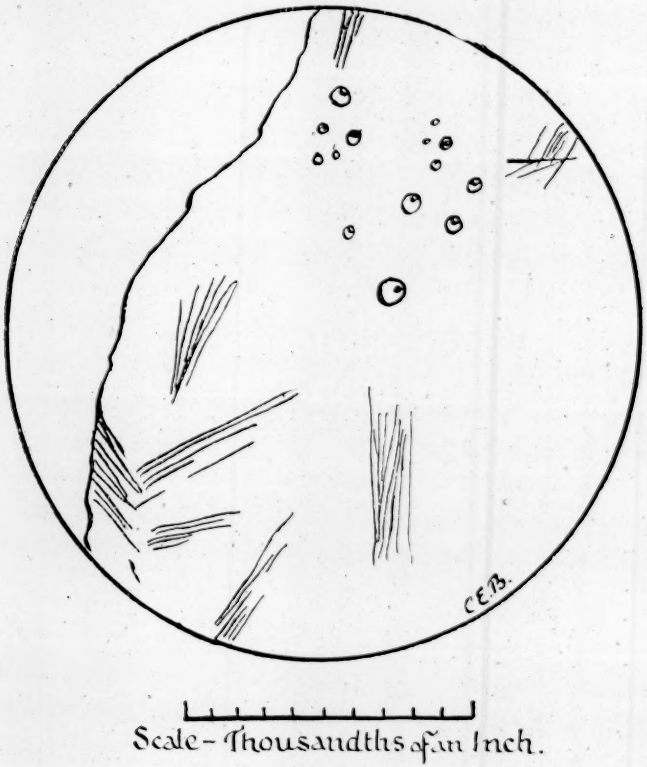


FIG. 3.—Liquid inclusions obtained in glass by heating a sealed tube containing water beyond the critical temperature.

P.S.—Since writing the above I have repeated the experiment with similar success, and on this occasion some of the numerous inclusions show Brownian movement of the enclosed bubble. —C. E. B.

The Igneous Complex of Y Foel Fras, Caernarvonshire.

By NORMAN L. SILVESTER, B.Sc., F.R.Met.Soc.

THE area under consideration is a portion of the mountain massif bounded on the east by the Conway River, on the north by the narrow coastal plain between Conway and Bangor, and on the west and south by the popular tourist route through Nant.-Francon pass by Llyn Ogwen and down the Afon Llugwy to Bettws y coed.

The investigation includes the horseshoe-shaped ring of mountains, of which the highest is Y Foel Frâs (3,091 feet), surrounding the upper course of the Aber River (Cwm yr Afon Goch). To the north-west this igneous complex is bounded by the precipitatious crags over which the above stream descends by leaps and bounds, forming the well-known Aber Falls. Upon Sheet 78, south-east of the old Geological Survey map the area is coloured as "Massive intrusive felspathic rocks", surrounding two oval patches indicated as "Greenstones", whilst a further elongated patch of the latter forms the south-west boundary. The north-east boundary is limited by the Aber-Llanbedr fault. Besides the hog-backed summit of Y Foel Frâs, the area includes the similarly outlined summits of Y Drosgl West [1] (2,483 feet), Yr Arryg (2,875 feet), Llwydmor Bâch (2,256 feet), and the more rugged summits of Bera Mawr (2,587 feet), Bera Bâch and Llwydmor (2,749 feet).

A study of this area commenced early in the summer of last year shows that the map will require considerable modification. The north-west boundary consists of a lenticular outcrop of augitic granophyre, nearly 3 miles in length, from north-east to south-west, and reaching a maximum width of about 1,200 yards at Y Drosgl West. The microstructure of the rock has been described by Dr. Harker [2] and an analysis published. The mass is undoubtedly intrusive as Ramsay remarks,[3] as for distances varying between about 30 and 100 feet from the contact the slates are baked to porcellanite. It is evident, however, that Ramsay mistook the baked slate which weathers yellow for the chilled edge of the intrusion. He mentions that the intrusion edge "rises like a wall, is fine grained and weathers yellow". A careful examination of the junction at the falls of the Afon Bâch shows that it is not at all regular, but that the granophyre sends veins into the baked sedimentaries. Also it is noticed that it is the indurated baked slate that forms the walls of the precipice in most places, and it is seen that this metamorphosed rock weathers better than the intrusion. This is well shown on the summit of Gyrn Wigau, where the only exposure is a well-defined ridge running from north to south, composed of this dark-grey porcellanite, weathering pale yellow, while the outcrop of the granophyre to the east of the ridge can be deduced only from scattered blocks.

The thermo-metamorphism of the contact rock is less pronounced than would be anticipated from the dimensions of the intrusion. A micro-slice cut from a specimen from the exposure at the lesser Aber Falls [4] shows no distinct recrystallization except for minute grains of magnetite which increase in number towards the junction.

[1] It is necessary to add the suffix "West" to distinguish this mountain from the other of the same name 3 miles north-east, i.e. between Foel Fras and Tal-y-fan.

[2] A. Harker, *Bala Volcanic Series of Rocks*, pp. 41–8.

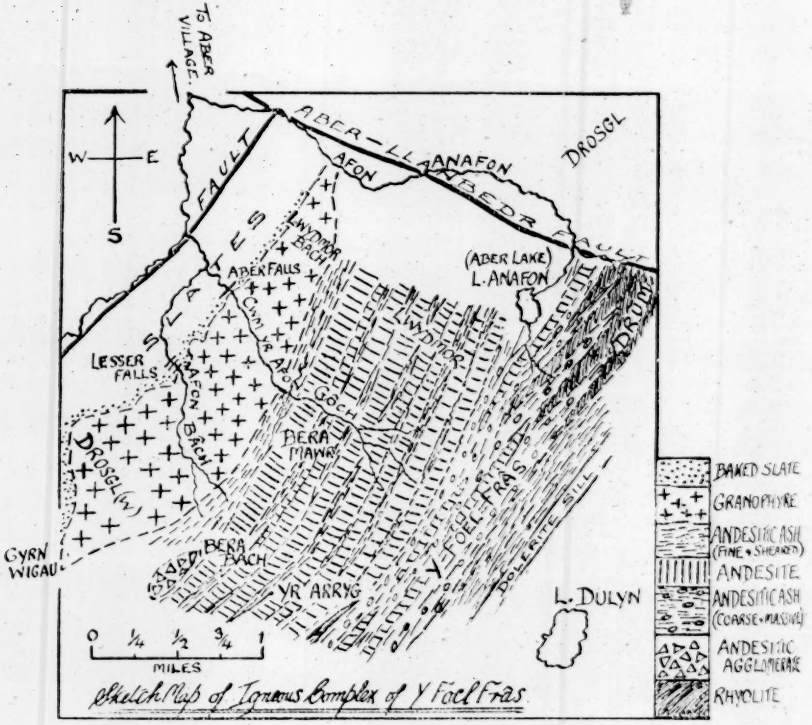
[3] Ramsey, *Geological Survey Memoir N. Wales*, pp. 138–9.

[4] Lent by Dr. E. Greenly.

By reflected light there seems to be a faint indication of the development of two minerals producing a vague spotted appearance.

At the base of the Aber Falls the slate shows distinct spotting in the hand specimens. This rock when sliced will probably reveal a greater development of contact minerals.

The granophyre, when followed up either the Afon Bâch or the Cwm yr Afon Gôch, becomes first much coarser in texture, then at a distance of 200 feet from the falls junction develops patches of darker hue, in which the dark minerals are segregated. Further



Sketch Map of Igneous Complex of Y Foel Fras

FIG. 1.—The Igneous Complex of Y Foel Fras.

upstream the rock becomes more fine-grained and darker and more homogeneous in the hand specimen, but still with occasional patches of coarser grain. Near the south-eastern margin of the intrusion the rock becomes sheared. This is of interest, as it appears to be evidence in favour of the theory put forward by Dr. A. Harker that the direction of the thrust which produced the great earth-movements in Bala times was from the south-east. There are no signs of shearing on the north-west margin. This phenomenon is best seen on the summit of Llwydmor Bâch.

No good exposure of the junction between the granophyre and the sheared andesitic ashes which succeed in outcrop in a south-east direction has as yet been found. This is owing to the comparative ease with which the latter beds have weathered—the weathering being assisted by the vertical cleavage. In neither of the above-mentioned streams is there any exposure—the solid geology of this area being obscured by drift. This band of ashes outcrops parallel to the general trend of the granophyre over a width of about 600 feet. It can be followed from the saddle between Llwydmor and Llwydmor Bâch across the Cwm yr Afon Gôch and up the northern slopes of Bera Mawr. The rock is hopelessly weathered, with abundant felspars showing occasionally a kernel of unweathered plagioclase.

Continuing the traverse up the Cwm yr Afon Gôch, the sheared ashes are succeeded by massive lava flows composed of andesite intercalated with sheared ashes of similar composition. Over these the stream rushes in a series of cascades, whilst in two places the stream has cut back its bed so that it now runs through a miniature cañon 30 feet deep and only 5 to 10 feet wide at the top. The andesite is usually of a dark-grey colour with conspicuous and numerous plagioclase phenocrysts. It weathers in the first stage to a greenish rock in which the felspars appear white. At a further stage—well seen in the exposed summits of Bera Mawr and Bera Bâch—the weathering agency has selected the felspar phenocrysts for destruction, so that the surface presents a rough vesicular appearance and is quite pale-grey with a lilac tinge. Owing to their proneness to weathering, the vesicular selvages of the individual flows are rarely exposed. The edge of the first flow is exposed in the crags on the left bank of the Afon Gôch just above the sheared ashes. Evidence from the orientation of the felspar phenocrysts and from measurements of the vesicular selvages of the flows, points to the fact that the strike of these lavas is S.S.W.–N.N.E., and the dip about 90°. These flows, with few intercalations of ashes, outcrop for about 1 mile in the direction of dip before they are succeeded by another andesitic series in which ashes predominate over flows. Many of these ashes are as massive and resistant to weathering as the massive flows which form the rugged summits of Bera Mawr, Bera Bâch, and Llwydmor. They are coarser than the sheared ashes, described above, the fragments of scoria occasionally measure 3 inches in diameter. They form the upper north-west slopes and summit of Foel Frâs. Near the summit the effects of pressure again become evident, as these beds when traced down the opposite south-east flank become gradually more sheared.

The massive andesites can be traced in the direction of their strike, a distance of over 2 miles from the western shore of Lake Anafon over Llwydmor and Bera Mawr to Bera Bâch. It has not been found possible up to the present to distinguish the individual

flows in the field by means of petrographic differences. The summit of Lwydmor as viewed from the valley of the Anafon below the lake consists of a succession of five flows whose basset edges stand out boldly against the skyline like the castellations on a castle wall, whilst on Bera Mawr they number six.

The proximity of the vent from which this andesitic series was extruded seems clearly evident from the occurrence immediately to the west of Bera Bâch of a small outcrop of coarse agglomerate or breccia consisting of large fragments of fine-grained vesicular andesite measuring as much as 2 ft. 6 in. in length. The interstices are filled with smaller fragments of ash, and the cementing material is a soft, dark slate in which no fossils could be found. Exposed as they are at a height of over 2,000 feet to the full force of the prevalent winds, these agglomerates are deeply weathered to a uniform pale grey, looking remarkably like weathered rhyolites in the distance. As the cementing material has weathered faster than the lava blocks, the latter stand out from the surface so as to resemble the loose débris of a recent eruption. The dip of the longer axes of most of the blocks is south-east at 70° to 80°.

According to Dr. Harker [1] the whole of the area consists of the plug of a vast volcano built on the site of and partly out of the fragments of an older vent. This hypothesis readily removes the difficulty of explaining the sudden disappearance of the series when traced in the direction of the strike to the north-east. It will also explain the vertical position of the lava flows if it is assumed that the plug successfully resisted the later earth-movements without being thrown out of the vertical. It is, however, not easy to account for the persistence of the strike of the lava flows. If they are merely the feeders which supplied the material for the ashes and for flows since removed by denudation, it is to be expected that their outcrop in cross section would be approximately circular unless the eruption were of the fissure type. If, on the other hand, this series represents the remains of a normal succession of flows and intercalated ashes originally laid down horizontally but since thrown on edge by crust movements, we have a succession nearly 2 miles thick comparable in magnitude to the Borrowdale series in the Lake District. At the eastern extremity of the area, as in the succession exposed in Pant y Mynach to the south of L. Anafon, rhyolitic flows and ashes become intercalated with the andesitic series. This rhyolitic series thickens north-eastward, but dies out in the opposite direction between Foel Frâs and Llwydmor. It therefore appears that the vicinity of Llyn Anafon is an area intermediate between two vents, one near Bera Bâch pouring out andesitic material simultaneously with another to the north-east ejecting more acid material. Ashes formed of fragments of both kinds are found on the west shore of Llyn Anafon.

[1] Harker, *Bala Volcanic Series of Rocks*, p. 127.

Evidence for the Aber-Llanbedr fault has been found near the source of a small tributary which enters the right bank of the Afon Anafon 500 yards below the lake, where rhyolites are found faulted against contorted slates. Fault breccias provide further evidence 500 yards lower down the Anafon, and also near the north-eastern extremity of the granophyre laccolith in the groove cut by a small stream which enters the left bank of the Anafon after draining the north slopes of Llwydmor Bach.

The area to the north-east and north-west of Llyn Anafon is much disturbed by faulting and needs further investigation. The work is being continued, and it is hoped that a map of the area on the 6 inch scale will be published at a later date together with a more detailed account.

REVIEWS.

EDINBURGH'S PLACE IN SCIENTIFIC PROGRESS. Prepared for the Edinburgh Meeting of the British Association by the Local Editorial Committee. pp. 263. W. & R. Chambers, Ltd., Edinburgh and London, 1921. Price 6*s.* net.

THIS record of Edinburgh's contributions to science is something very much more than the usual type of British Association Handbook. Written by twenty-five different authors, each of whom is a specialist in his own branch of knowledge, this work should be of paramount value as a history of the influence of the Scottish capital upon scientific advancement. The article on geology is by Messrs. E. B. Bailey and D. Tait, of H.M. Geological Survey of Scotland, and it contains an admirable record of the continuity of geological thought as shown especially in the important part played by Edinburgh men in the developmental progress of the subject from the seventeenth century down to our own time. Beginning with a reference to Sinclar and his *Short History of Coal*, published in 1672, the authors proceed to the consideration of the life and work of James Hutton, the writer of *The Theory of the Earth*, about which so much controversy centred. This brings them to Playfair and Hall, Hutton's distinguished supporters, and to Jameson, the local representative of the opposing Wernerian school, all three of whom were Edinburgh men. Among the other famous geologists whose work is alluded to are Williams, Fleming, Paterson, Hugh Miller, and Edward Forbes. The authors have made no attempt to bring their history uniformly up-to-date, but we are glad to see that they have not altogether omitted the work of the later geologists, including some who are happily still living. We have no space for a review of the other articles, but reference must be made to Mr. Stewart's account of the oil-shale industry, and Sir William Herdman's article on modern oceanography, of which subject he justly remarks that Edinburgh is its birthplace and its home.

F. H. A. M.

LIFE IN A SUSSEX WINDMILL, WITH SOME AMENITIES OF THE SOUTH DOWNS. By EDWARD A. MARTIN, F.G.S. pp. 118, with illustrations. Allen & Donaldson, Ltd., London, 1921. Price 6*s.* net.

THIS book contains a pleasantly written account of life in a disused windmill, where the author took up his abode for a season in order that he might write and think in peaceful retirement. A good deal of the matter, without being original, is of interest to the geologist, and there are chapters on the "Eight Downland Quadrilaterals", the "Dry Coombes and Bournes of the Downs", "Ancient Man on the Downs", and "Sussex Coal, Iron, and Wood". Perhaps, however, the most interesting chapter is one "About Dewponds", on which the author has made a number of

careful and original observations. The illustrations, which consist of local sketches and photographs and figures of fossils, are of no especial value.

F. H. A. M.

Die Fossilen Kohlen Bosniens und der Hercegovina. By Dr. F. Katzer. Vols. I and II. pp. 403 and 271, with 145 text-figures and two folding geological maps. Sarajevo : 1921.

THE provinces of Bosnia and Herzegovina, formerly included within the Austrian Empire, and now constituting part of the new Serb-Croat-Slovene State (or Yugoslavia), have extensive coal deposits, which appear likely to prove of great potential importance to the new State. Under the ægis of the former Austrian Government, these provinces were originally surveyed and described by Bittner, Tietze, and Mojsisovics; and for the past thirty years their work has been continued by Dr. F. Katzer, at one time Professor of Geology at the University of Prague.

In the present work the author gives a detailed account of the geology of the several coalfields, many of which were opened up by the Central Powers under the stress of urgent war demands.

All the coals likely to be of any economic importance in these provinces belong to the Tertiary Formation. The occurrence of coal at several localities in the Carboniferous, Permian, Lower Trias, and Cretaceous Formations is recorded, but none appear to be of any extent. The workable coals occur at two principal horizons; one of Lower Miocene or Upper Oligocene age, and the other of Lower Pliocene age.

The most important Bosnian coalfield lies to the north and west of Sarajevo, and has an area of about 350 square miles. Zenitsa, Kakanj, and Breza are the principal collieries. The coals occur in a varying series of freshwater limestones, marls, and shales; the fauna and flora of which show the closest resemblances to those of the Sotzka Series, described from the Upper Drave valley in Carniola by the Austrian Survey; and which have close affinities with both the Upper Oligocene and Lower Miocene Formations of Western Europe. In describing these beds Dr. Katzer employs the non-committal term Oligo-Miocene. The second coal-field of importance is in the neighbourhood of Tuzla, the chief industrial centre in Northern Bosnia, where lower grade Pliocene coals are being mined. These coals are considered to be of Pontian or Lower Pliocene age, and with them are associated "Congeria" marls and clays, a facies generally believed to have a wide development in the Balkans. There are several seams of very pure lignitic coal, some of which attain a thickness of over 60 feet.

Among the remaining Bosnian coalfields, the principal in order of importance are: Banjaluka and Koto Varos, in North-Western Bosnia; Uglyevik and Priboj, in North-Eastern Bosnia; and Livno, close to the Dalmatian provincial boundary.

The coal resources of Herzegovina are relatively insignificant. A small Oligo-Miocene coal basin occurs in the immediate vicinity of Mostar, and is being worked, while smaller detached areas are described as flooring many of the poljes which form so distinctive a feature of the otherwise barren Herzegovinian limestone plateau.

From his exhaustive study of the several areas, Dr. Katzer estimates that the total quantity of coal available in the coalfields of Bosnia and Herzegovina may safely be computed at 758 million metric tons, of which 20 per cent consist of Oligo-Miocene brown coal, while the remaining 80 per cent consist of the lower grade Pliocene lignitic coals. Adding to this the possible coal resources in areas not completely surveyed, which amount to no less than 4,941 million metric tons, it will be seen that Bosnia has, probably of all Balkan lands, by far the richest fuel resources; a valuable asset to a State like Yugoslavia, whose industrial developments have only reached an embryonic stage.

Each volume is accompanied by a useful folding geological map, the first by a coloured map of the Sarajevo-Zenitsa coalfield on a scale of 1 : 75,000, and the second by a coloured map of the coalfields of Bosnia and Herzegovina on a scale of 1 : 750,000.

D. A. Wray.

Schweizerische Mineralogische und Petrographische Mitteilungen. Band I, Heft 1/2. pp. 1–214, 1921. Huber and Co., Frauenfeld.

To those geologists who have found access to the petrographical literature of Switzerland, a matter of some difficulty, the appearance of a new journal devoted to Swiss mineralogy and petrology will be especially welcome. Hitherto much Swiss petrology has appeared in "dissertation" form, or as papers in local journals of very limited circulation; few libraries indeed, in this country, would, for instance, possess volumes of the *Jahresbericht der Naturforsch. Gesellschaft Graubündens*. It is to the interest of geological science that its publications be segregated as far as possible in specialized journals, and not diffused through organs embracing the whole gamut of science, and in this connexion, to refer to imperial geology, the example of the Geological Society of South Africa might well be followed with advantage in other dominions of the Empire. The new Swiss journal now appearing will doubtless make available, in a readily accessible form, work otherwise almost lost to other countries. In the present number five articles are contributed — all in German — and include studies on the serpentine and talc of Disentis Surrhein, the wolfram deposits of the Argentine, the radioactivity of some Swiss rocks, a petrographic study of the region of Piz Languard (Oberengadin), and on the fluorspar of Sembrancher (Wallis).

The journal is published under the editorship of Professor Grubenmann, with an annual subscription rate of 25 francs.

C. E. T.

REPORT ON THE CROCODILE RIVER IRON DEPOSITS. By P. A. WAGNER. Geological Survey of the Union of South Africa, Memoir No. 17. pp. 65, with 12 plates and 5 figures. 1921.

THESE deposits of banded hæmatite ore are situated in the northern part of the Rustenburg district of the Transvaal, in a rather inaccessible district, 68 miles from the nearest railway. They lie immediately above the dolomite of the Transvaal System, and belong to the usual type of banded ironstone that is so common in many localities. They include red and black, black and grey, and dull-brown varieties, as well as calico-rock, and may be described as essentially banded ferruginous cherts with a varying proportion of iron oxide; the iron-content ranges from 16 to 44 per cent, but the silica is usually very high. It seems highly probable that when a railway is constructed these deposits will become of economic importance.

CORRESPONDENCE.

PALÆONTOLOGICAL ABSTRACTS.

SIR,—You allowed me in April, 1920, to draw attention to the alliance of the *Revue Critique de Paléozoologie* with the *Review of Geology*. May I remind your readers that the work of preparing or editing abstracts of all papers on fossil animals and plants is still carried on by M. Cossmann, and that he is particularly anxious to receive either author's abstracts or separate copies of all papers by British palæontologists.

Will those who respond to his request kindly note the new address: from November to May, 21 Rue Montpensier, Pau (B.-P.), France; from June to October, 2 Boulevard Sadi-Carnot, Enghien (S. & O.), France.

F. A. BATHER.

THE RAISED BEACH AT EASINGTON.

SIR,—Having had the privilege of examining the Durham coast-sections last summer under the guidance of Dr. Trechmann and Dr. Woolacott, I can thoroughly appreciate the importance of their discoveries among the Pleistocene deposits, which have introduced new factors into the complicated problems of the East British drifts.

On seeing the Raised Beach at Easington, discovered by Dr. Woolacott and discussed by him in your current (February) issue, I was immediately satisfied that it was an actual marine shore-deposit resting upon its original rock-shelf, and a later visit confirmed me in this opinion. But I saw in the same neighbourhood, and elsewhere in the county, other sandy and gravelly deposits, to which a marine origin has been assigned, that appeared to me to be all of the usual fluvio-glacial type, carrying no positive evidence of marine conditions and differing essentially from the Easington Beach.